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Equivalent Safety Evaluation of the 2021 Edition of the ASME Boiler and Pressure Vessel Code to Editions Incorporated by Reference in 49 CFR 192, 193, and 195

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March 2022

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MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

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Energy Science and Technology Directorate
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ACRONYMS AND ABBREVIATIONS

°C	Degree Celsius
°F	Degree Fahrenheit
ACCP	ASNT Central Certification Program
AHJ	Jurisdiction Having Authority
AIA	Authorized Inspection Agency
API	American Petroleum Institute
ASME	American Society for Mechanical Engineers
ASTM	American Society for Testing and Materials
AWS	American Welding Society
BPQ	Brazer or Brazing Operator Performance Qualification
BPS	Brazing Procedure Specification
BPV	Boiler and Pressure Vessel
BPVC	Boiler and Pressure Vessel Code
CAR	Conformity Assessment Requirement
CEN	European Committee for Standardization
CFR	Code of Federal Regulations
CR	Computed Radiography
CSA	Canadian Standards Association
CSC	China Standardization Committee
CSEF	Creep Strength Enhanced Ferritic
DAC	Distance–Amplitude Correction
DB	Dip Brazing
DDS	Digital Detector System
DFW	Diffusion Welding
DMW	Dissimilar Metal Weld
DOT	Department of Transportation
DR	Digital Radiography
EBW	Electron Beam Welding
ECA	Eddy Current Array
EGW	Electrogas Welding
ESW	Electroslag Welding
ET	Eddy Current
FB	Furnace Brazing
FCAW	Flux-Cored Arc Welding
FFS	Fitness-for-Service
FMC	Full Matrix Capture
FPQ	Fusing Operator Performance Qualification Record
FPS	Fusing Procedure Specification
FSW	Friction Stir Welding
ft-lb	Foot-pound
GMAW	Gas Metal Arc Welding
GTAW	Gas Tungsten Arc Welding
HAZ	Heat Affected Zone
HCF	High-Cycle Fatigue
HDPE	High Density Polyethylene
HFI	High Frequency Welding
HMSLD	Helium Mass Spectrometer Leak Detector
hr.	Hour

HRSG	Heat Recovery Steam Generators
IB	Induction Brazing
IBR	Incorporated by Reference
in.	Inch
IQI	Image Quality Indicator
JIS	Japan Industrial Standards
LBW	Laser Beam Welding
LCF	Low-cycle Fatigue
LEFM	Linear Elastic Fracture Mechanics
LLBW	Low-Power Density Laser Beam Welding
LNG	Liquefied Natural Gas
LSR	Lowest Stress Ratio
LTA	Local Thin Areas
MAWP	Maximum Allowable Working Pressure
MDMT	Minimum Design Metal Temperature
MHz	Megahertz
mm	Millimeter
MPa	Megapascal
MT	Magnetic Particle Examination
NB	National Board of Boiler and Pressure Vessel Inspectors
NBIC	National Board Inspection Code
NDE	Nondestructive Examination
NFPA	National Fire Protection Association
OFW	Oxyfuel Gas Welding
OPS	Office of Pipeline Safety
PAUT	Phased Array Ultrasonic
PAW	Plasma Arc Welding
PCS	Probe Center Spacing
PED	Pressure Equipment Directive
PHE	Plate Heat Exchanger
PHMSA	Pipeline and Hazardous Materials Safety Administration
PMI	Positive Material Identification
PMIP	Positive Material Identification Practice
PQR	Procedure Qualification Record
psi	Pounds per square inch
psig	Pounds per square inch, gage
PT	Liquid Penetrant Examination
PVRC	Pressure Vessel Research Council
PWHT	Postweld Heat Treatment
RB	Resistance Brazing
RT	Radiographic Examination
SAA	Standards Association of Australia
SAW	Submerged Arc Welding
SCC	Stress Corrosion Cracking
SDH	Side Drilled Hole
SMAW	Shielded Metal Arc Welding
TB	Torch Brazing
TC	Thermal Conductivity
TD	Thermal Diffusivity
TOFD	Ultrasonic Time of Flight Diffraction
UDS	User's Design Specification

UNS	Unified Numbering System
UT	Ultrasonic Examination
UTS	Ultrasonic Tensile Strength
VT	Visual Examination
WPQ	Welder/Welding Operator Performance Qualification
WPS	Welding Procedure Specification

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Most respectfully,

Simon D. Rose, C. Barry Oland, and Mark D. Lower

ABSTRACT

Federal safety standards for natural gas and hazardous liquid pipelines and liquid natural gas facilities incorporate rules and requirements for boiler and pressure vessel design and fabrication into 49 CFR Parts 192, 193, and 195 through the IBR process. The equivalent safety evaluations documented in this report demonstrate that boilers and pressure vessels in pipeline facilities that are designed and fabricated in accordance with rules and requirements specified in the 2021 edition do not violate the fundamental safety assumptions stated or implied in the 2007 edition of the ASME BPVC and therefore provide equivalent safety.

EXECUTIVE SUMMARY

The Pipeline and Hazardous Materials Safety Administration (PHMSA) within the U.S. Department of Transportation is the safety authority responsible for establishing Federal safety standards for natural gas and hazardous liquid pipelines including LNG facilities. These standards are published in 49 Code of Federal Regulations (CFR) Parts 192, 193, and 195.

Rather than promulgating pipeline safety regulations for boilers; pressure vessels; and the production, storage, and handling of LNG, PHMSA incorporates applicable requirements published by American Society of Mechanical Engineers (ASME) International, the American Petroleum Institute (API), and the National Fire Protection Association (NFPA) into 49 CFR Parts 192, 193, and 195 through the IBR process. The IBR codes and standards with requirements for boilers and pressure vessels were published on or before 2007.

The ASME Boiler and Pressure Vessel Code (BPVC) is a consensus standard that specifies requirements for design and fabrication of boilers and pressure vessels. Editions of the ASME BPVC are published on July 1 of odd numbered years and are in effect for a two-year period. Boilers and pressure vessels that are constructed in accordance requirements in a preceding edition cannot receive a Certification Mark. Table E.1 lists the sections of the 2007 and 2021 editions of the ASME BPVC that are the subject of this report.

Table E.1 Sections of the ASME BPVC evaluated for equivalent safety

Section	Title
I	Rules for Construction of Power Boilers (See Note 1)
II	Materials (See Note 2)
V	Nondestructive Examination (See Note 2)
VIII, Div. 1	Rules for Construction of Pressure Vessels (See Note 1)
VIII, Div. 2	Rules for Construction of Pressure Vessels – Alternative Rules (See Note 1)
IX	Qualification Standard for Welding, Brazing, and Fusing Procedures; Welders; Brazers; and Welding, Brazing, and Fusing Operators (See Note 2)
XIII	Rules for Overpressure Protection (See Note 2 and 3)

Notes:

1. Construction Code – provides rules for materials, design, fabrication, examination, inspection, testing, certification, and pressure relief. Construction Codes refer to Reference Codes.
2. Reference Code – provides standards for materials, welding and brazing procedures and qualifications, and nondestructive examination that are referenced by the Construction Codes.
3. Section XIII was introduced into the ASME BPVC in the 2021 edition.

To the extent practicable, PHMSA is authorized to ensure that pipeline safety regulations are consistent with safety requirements specified in IBR consensus codes and standards. This report provides rationale and justification for concluding that the rules and requirements specified in Section I; Section VIII, Division 1; and Section VIII, Division 2 in the 2021 edition of the ASME BPVC are equivalent in safety to the corresponding rules and requirements specified in Section I; Section VIII, Division 1; and Section VIII, Division 2 in the 2007 edition of the ASME BPVC.

Safety equivalency evaluation results described in this report were determined using a combination of quantitative and qualitative comparative analyses of rules specified in the 2007 and 2021 editions of the

ASME BPVC. The safety baseline for comparison is the 2007 edition of the ASME BPVC. These equivalent safety evaluations:

- focus primarily on materials; design including failure modes, strength theories, and principles of limit design theory; fabrication and inspection including nondestructive examinations; pressure testing; and overpressure protection.
- demonstrate that boilers and pressure vessels in pipeline facilities that are designed and fabricated in accordance with rules and requirements specified in the 2021 edition do not violate the fundamental safety assumptions stated or implied in the 2007 edition of the ASME BPVC and therefore provide equivalent safety.

E.1 MATERIALS

Section II of the ASME BPVC provides specifications and properties for materials permitted for construction of boilers and pressure vessels. These specifications are identified in Section II, Part A – Ferrous Material Specifications, Part B – Nonferrous Material Specifications, Part C – Specifications for Welding Rods, Electrodes, and Filler Metals. The 2021 edition of Section II adds 28 specifications that were not included in the 2007 edition and excludes three specifications that were included in the 2007 edition.

The Preface to the 2021 edition of Section II, Part A of the ASME BPVC provides additional information about the way existing material specifications are revised and new materials specifications are incorporated into Section II. It states:

> *The ASME Boiler and Pressure Vessel Committee has given careful consideration to each new and revised specification, and has made such changes as they deemed necessary to make the specification adaptable for Code usage. In addition, ASME has furnished ASTM with the basic requirements that should govern many proposed new specifications. Joint action will continue an effort to make the ASTM, AWS, and ASME specifications identical.*

Section II, Part D, Mandatory Appendix 5 in the 2021 edition of the ASME BPVC provides further guidelines on the approval of new materials under the ASME Code.

Section II, Part D – Properties of the ASME BPVC provides stress tables and tables of mechanical and physical properties corresponding to each of the material specifications included in Section II, Parts A and B of the ASME BPVC. These values are used as input to design calculations performed in accordance with rules specified in the Construction Code.

Stress tables in Section II, Part D in the 2007 and 2021 editions of the ASME BPVC specify maximum allowable stress values, S, (Tables 1A, 1B, 3, 5A, and 5B) and design stress intensity values, S_m, (Tables 2A, 2B, and 4). Tables U and Y-1 provide tensile strength values and yield strength values, respectively, for ferrous and nonferrous materials. Physical properties (thermal conductivity, thermal diffusivity, thermal expansion, and density), Young's modulus, and Poisson's ratio values are tabulated in Section II, Part D, Tables TE, TCD, TM, and PRD of the ASME BPVC.

Maximum allowable stress values given in Table 1A and Table 1B are used to design boilers and pressure vessels in accordance with rule specified in the 2021 editions of Section I and Section VIII, Division 1. Design stress intensity values given in Table 2A and Table 2B are used to design Class 1 pressure vessel in accordance with rule specified in the 2021 edition of the Section VIII, Division 2. Design stress intensity values given in Table 5A and Table 5B are used to design Class 2 pressure vessel in accordance with rule specified in the 2021 edition of the Section VIII, Division 2.

E.2 DESIGN

Design and fabrication rules specified in the ASME BPVC provide assurance that a boiler or pressure vessel will provide safe and satisfactory performance during its useful service life. However, compliance with these rules does not ensure a long service life nor does it guarantee a minimum design margin of 1.5 against plastic collapse when the loadings and environmental conditions are more severe that those represented in the design basis. According to rules specified in the ASME BPVC, users are responsible for establishing the design basis for a boiler or pressure vessel, and the designer is responsible for ensuring that the specified stress limits are not exceeded under all operating conditions defined by the user.

E.2.1 Failure Modes

The failure categories for boilers and pressure vessel are organized into four groups: (1) materials, (2) design, (3) fabrication, and (4) service. The various possible modes of failure which confront boiler and pressure vessel designers are:

- Excessive elastic deformation including elastic instability – Design and Fabrication
- Excessive plastic deformation (ductile rupture) – Design and Material
- Brittle fracture – Design, Material, and Fabrication
- Stress rupture / creep deformation (inelastic) – Design, Material, and Service
- Plastic instability – incremental collapse – Design and Service
- High strain – low-cycle fatigue – Design and Service
- Stress corrosion – Service
- Corrosion fatigue – Service

Evaluations of rules provided in the 2007 and 2021 editions of the ASME BPVC for controlling these failure modes were conducted to determine equivalent safety.

E.2.1.1 Excessive Elastic Deformation Including Elastic Instability

Excessive elastic deformation (deflection) and elastic instability (buckling) cannot be controlled by imposing upper limits on calculated stress alone because these behavioral phenomena are affected by component geometry, stiffness, and material properties. The designer of a boiler or pressure vessel is responsible for applying engineering principles to understand and avoid in-service problems or failures caused by excessive elastic deformation and elastic instability through proper application of design rules and specified stress limits.

The 2007 and 2021 editions of Section I and Section VIII, Division 1 use charts and tables for determining the shell thickness of components under external pressure, but Section VIII, Division 2 provides rules for three alternative types of buckling analysis to evaluate structural stability from compressive stress fields. These excessive elastic deformation and elastic instability rule changes were evaluated and found to provide equivalent safety.

E.2.1.2 Excessive Plastic Deformation (Ductile Rupture)

The plastic deformation mode of failure (ductile rupture) is controlled by imposing limits on calculated stress. Primary stress limits and primary plus secondary stress limits in the ASME BPVC are intended to prevent excessive plastic deformation leading to incremental collapse and to provide a nominal margin on the ductile burst pressure. The designer of a boiler or pressure vessel is responsible for ensuring that the specified stress limits are not exceeded under all operating conditions defined by the user.

Rules for protection against plastic collapse are not explicitly stated in Section I or Section VIII, Division 1 of the ASME BPVC, but rules for avoiding excessive plastic deformation are provided in Part 5, Paragraph 5.2 – Protection Against Plastic Collapse in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC.

The maximum allowable stress for boilers and pressure vessels constructed in accordance with rules specified in the 2007 and 2021 editions of Section I; Section VIII, Division 1; and Section VIII, Division 2 of the ASME BPVC is limited to two-thirds of the yield strength of the material, $2/3\,S_y$, or less. This limit provides protection against plastic collapse and prevents excessive plastic deformation by ensuring elastic response for all operating conditions.

E.2.1.3 Brittle Fracture

Brittle fracture is a failure mode that can occur without appreciable prior plastic deformation in metals that are under tensile stress. When local stresses in the area of a flaw reach the yield point, the metal may tear or form a crack, which can then grow suddenly through the thickness causing a catastrophic failure. The ability of a metal to resist tearing or cracking is a measure of its fracture toughness. Fracture toughness is a material property that often varies with temperature. According to linear elastic fracture mechanics (LEFM) theory, allowable stress in the presence of a given crack size is proportional to the fracture toughness.

Rules for avoiding brittle fracture focus on fracture toughness and vary from one Section and edition of the ASME BPVC to another. However, no fracture toughness requirements are specified in either the 2007 or the 2021 edition of Section I of the ASME BPVC because boilers operate at elevated temperatures where brittle fracture is a very unlikely mode of failure.

A comparison of toughness requirements specified in the 2007 and 2021 editions of the ASME BPVC is presented in Table 4.1 of this report. Based on this comparison, the minimum lateral expansion values for Charpy V-notch specimens permitted in the 2021 edition for materials listed in Table 3-A.1 – Carbon and Low Alloy Steel Materials Except Bolting Materials are approximately 30% greater than the minimum lateral expansion values permitted in the 2007 edition of Section VIII, Division 2 of the ASME BPVC. Consequently, toughness requirements in the 2021 edition of Section VIII, Division 2 of the ASME BPVC for materials listed in Table 3-A.1 are more stringent than those in the 2007 edition for materials listed in Table 3-A.1. The remainder of the toughness requirements specified in the 2021 edition provide equivalent safety to the toughness requirements specified in the 2007 editions of the ASME BPVC.

E.2.1.4 Stress Rupture / Creep Deformation (Inelastic)

Boiler and pressure vessel materials that are in service above a certain temperature undergo continuing deformation (creep) at a rate that is strongly influenced by both stress and temperature. The temperature at which creep occurs varies with the alloy composition. In order to prevent excessive deformation and possible premature rupture it is necessary to limit the allowable stresses by additional criteria on creep-rate and stress-rupture. In this creep range of temperatures, these criteria may limit the allowable stress to substantially lower values than those suggested by the usual factors on short time tensile and yield strengths.

Historically, the official ASME position has been that a design in the creep range has no implied maximum duration. When setting allowable stress limits, ASME uses the average and minimum

100,000 hr. stress rupture strengths of a material and also considers a conservative estimate of 10^{-7}/hr. for the creep (strain) rate. Therefore, the allowable stresses specified in the 2007 and 2021 editions of Section II, Part D of the ASME BPVC at temperatures in the range where creep and stress rupture strength govern are the same.

E.2.1.5 Plastic Instability – Incremental Collapse

Ratcheting is defined as a progressive incremental inelastic deformation or strain that can occur in a component subjected to variations of mechanical stress, thermal stress, or both. Ratcheting is produced by a sustained load acting over the full cross section of a component, in combination with a strain controlled cyclic load or temperature distribution that is alternately applied and removed. Ratcheting results in cyclic straining of the material, which can cause failure by fatigue and at the same time produces cyclic incremental deformation, which may ultimately lead to collapse.

No plastic instability and incremental collapse requirements associated with ratcheting are specified in either the 2007 or the 2021 edition of Section I or Section VIII, Division 1 of the ASME BPVC. Rules for ratcheting assessments are specified in Part 5, Paragraphs 5.5.6 – Ratcheting Assessment — Elastic Stress Analysis and 5.5.7 – Ratcheting Assessment — Elastic–Plastic Stress Analysis in the 2007 and 2021editions of Section VIII, Division 2 of the ASME BPVC. Protection against ratcheting must be considered for all operating loads listed in the User's Design Specification and must be performed even if the fatigue screening criteria are satisfied. The rules for ratcheting assessments specified in Part 5, Paragraphs 5.5.6 and 5.5.7 are the same in the 2007 and 2021editions of Section VIII, Division 2 of the ASME BPVC.

E.2.1.6 High Strain – Low-Cycle Fatigue

Fatigue is the weakening of a material caused by repeatedly applied loads. It is the progressive and localized material degradation that occurs when a component is subjected to cyclic loading. If the loads are above a certain threshold, microscopic cracks will begin to form at stress concentrations such as square holes or sharp corners. Eventually the crack will reach a critical size, propagate, and cause the component to fracture. Avoidance of discontinuities that increase local stresses will increase the fatigue life of a component subjected to cyclic loading.

There are two basic forms of fatigue that can adversely affect a boiler or pressure vessel. High-cycle fatigue (HCF) is characterized by low amplitude high frequency elastic strains. Low-cycle fatigue (LCF) is characterized by high amplitude low frequency plastic strains. The primary difference between HCF and LCF is the fact that the former involves little or no plastic action, whereas failure in a few thousand cycles can be produced only by strains in excess of the yield strain. In the plastic region, large changes in strain can be produced by small changes in stress.

The ASME BPVC establishes fatigue margins based on two considerations: (1) a factor of twenty on the number of cycles, and (2) a factor of two on stress. Studies of fatigue test data show that 10,000 cycles are the approximate border between LCF and HCF and a factor of twenty on the number of cycles has little effect at a high number of cycles. Consequently, a factor on stress was introduced as a margin at the higher number of cycles. A factor of two on stress gives approximately the same margin as a factor of twenty on cycles.

Boilers are generally not subjected to cyclic loading. Consequently, no fatigue requirements are specified in either the 2007 or the 2021 edition of Section I of the ASME BPVC. Plastic instability and incremental collapse requirements are also not specified in either the 2007 or the 2021 edition of Section VIII, Division 1 of the ASME BPVC. The 2007 and 2021 editions of Section VIII, Division 2 of the ASME

BPVC provides more comprehensive rules for fatigue assessment. These fatigue assessment rules cover: (1) elastic stress analysis and equivalent stresses, (2) elastic plastic stress analysis and equivalent strains, and (3) fatigue assessment of welds. The rules for performing a fatigue screening and fatigue evaluation are the same in the 2007 and 2021editions of Section VIII, Division 2 of the ASME BPVC.

E.2.1.7 Stress Corrosion and Corrosion Fatigue

Corrosion is a surface phenomenon that exhibits the gradual destruction of metals by chemical or electrochemical reactions with their environment. There are many types of corrosion that can cause deterioration of boiler and pressure vessel components. Two common types of corrosion that can adversely affect the integrity of a boiler or pressure vessel include stress corrosion cracking and corrosion fatigue.

Stress corrosion cracking (SCC) is the growth of crack formation in a corrosive environment and is highly chemically specific in that certain alloys are likely to undergo SCC only when exposed to a small number of chemical environments. The chemical environment that causes SCC for a given alloy is often one which is only mildly corrosive to the metal otherwise. The specific environment is of crucial importance, and only small concentrations of certain highly active chemicals are needed to produce catastrophic cracking, often leading to devastating and unexpected failure.

Corrosion fatigue is the mechanical degradation of a material under the joint action of corrosion and cyclic loading and can only occurs when the metal is under tensile stress. The rate of fatigue crack growth is enhanced by corrosion.

According to ASME BPVC rules, users or their designated agents are responsible for assuring that the materials used for construction of boilers and pressure vessels are suitable for the intended service conditions with respect to mechanical properties, resistance to corrosion, erosion, oxidation, and other damage mechanisms anticipated during service life. Protection against environmental conditions such as corrosion is the responsibility of the designer when included in the design basis. This protection is normally accomplished by selecting corrosion resistant materials and adding a corrosion allowance to the required minimum thickness of a component. The corrosion allowance does not need to be the same for all parts of a boiler or pressure vessel. However, the ASME BPVC does not provide mandatory requirements for corrosion allowances.

E.2.2 Strength Theories

The stress state at any point in a boiler or pressure vessel is completely defined by the magnitudes and directions of the three principal stresses. When two or three of these stresses are different from zero, the proximity to yielding must be determined by means of a strength theory. The following strength theories are often used in engineering applications.

- maximum stress theory
- maximum shear stress theory (also known as the Tresca yield criterion)
- distortion energy theory (also known as the octahedral shear theory and the von Mises criterion)

The specific strength theory used as the basis for design rules specified in the ASME BPVC varies from one Construction Code to another.

The maximum stress theory states that the controlling stress is the largest of the three principal stresses. The Tresca criterion represents a critical value of the maximum shear stress in a material while the von Mises criterion represents a critical value of the distortional energy stored in a material. The maximum shear stress theory (Tresca) and the distortion energy theory (von Mises) are both much better than the maximum stress theory for predicting both yielding and fatigue failure in ductile metals. It is also important to note that rules specified in the ASME BPVC based on these strength theories are only applicable to homogenous materials with isotropic material properties.

Equations specified in Section I and Section VIII, Division 1 of the ASME BPVC for determining wall thickness are, by implication, consistent with the maximum stress theory. Beginning with the 2007 edition of Section VIII, Division 2 of the ASME BPVC:

- the specified design-by-rule equations in Part 4 are based on a limit analysis using the Tresca yield criterion that has a three-dimensional yield or limit surface.
- Paragraph 5.2.2.1*(b)* in the 2007 and 2021 editions of the ASME BPVC state that the maximum distortion energy yield criterion shall be used to establish the equivalent stress.

E.2.3 Principles of Limit Design Theory

The theory of limit analysis defines a lower bound to the limit load of a component as the solution of a numerical model in which the material is assumed to exhibit elastic-perfectly plastic behavior at a specified yield strength, S_y. In a solid bar with a rectangular cross section made from elastic-perfectly plastic material, limit design theory predicts 'collapse' of the bar under either of the following loading conditions.

(1) Collapse occurs whenever the bar is subject to an axial tensile stress, P_m, equal to the yield strength, S_y. When expressed as an equation, collapse occurs when $P_m = S_y$.

(2) Collapse occurs whenever the bar is subject to a bending stress, P_b equal to the yield strength, S_y, times a shape factor equal to 1.5. When expressed as an equation, collapse occurs when $P_b = 1.5\, S_y$.

The following equation was derived by summing moments about the neutral axis of a solid bar with a rectangular cross section subjected to combined axial and bending stresses.

$$P_b/S_y = 1.5\left[1 - \left(P_m/S_y\right)^2\right] \qquad \text{for } 0 \le P_m/S_y \le 1.0$$

This equation, which defines the plastic collapse stress limit envelope shown in Fig. E.1, establishes the plastic collapse stress limit on which the maximum allowable stresses, hydrostatic and pneumatic test pressure limits, and overpressure protection requirements in the 2007 and 2021 editions of the ASME BPVC are based.

Application of the principles of limit design theory is the fundamental reason for concluding that the corresponding plastic collapse rules, hydrostatic and pneumatic pressure test rules, and overpressure protection rules in Section I; Section VIII, Division 1; and Section VIII, Division 2 in the 2007 and 2021 editions of the ASME BPVC provide equivalent safety.

E.3 FABRICATION AND INSPECTION

The term "fabrication" is not explicitly defined in the ASME BPVC, but it is generally understood to mean all activities a manufacturer uses to process and assemble plates, pipes, tubes, and other material products into a complete boiler or pressure vessel consistent with applicable rules in the ASME BPVC. Fabrication activities often involve a broad range of manufacturing methods and processes such as forming, machining, bolting, welding, brazing, and heat treating. These methods and processes tend to change as construction technology evolves and improves over time.

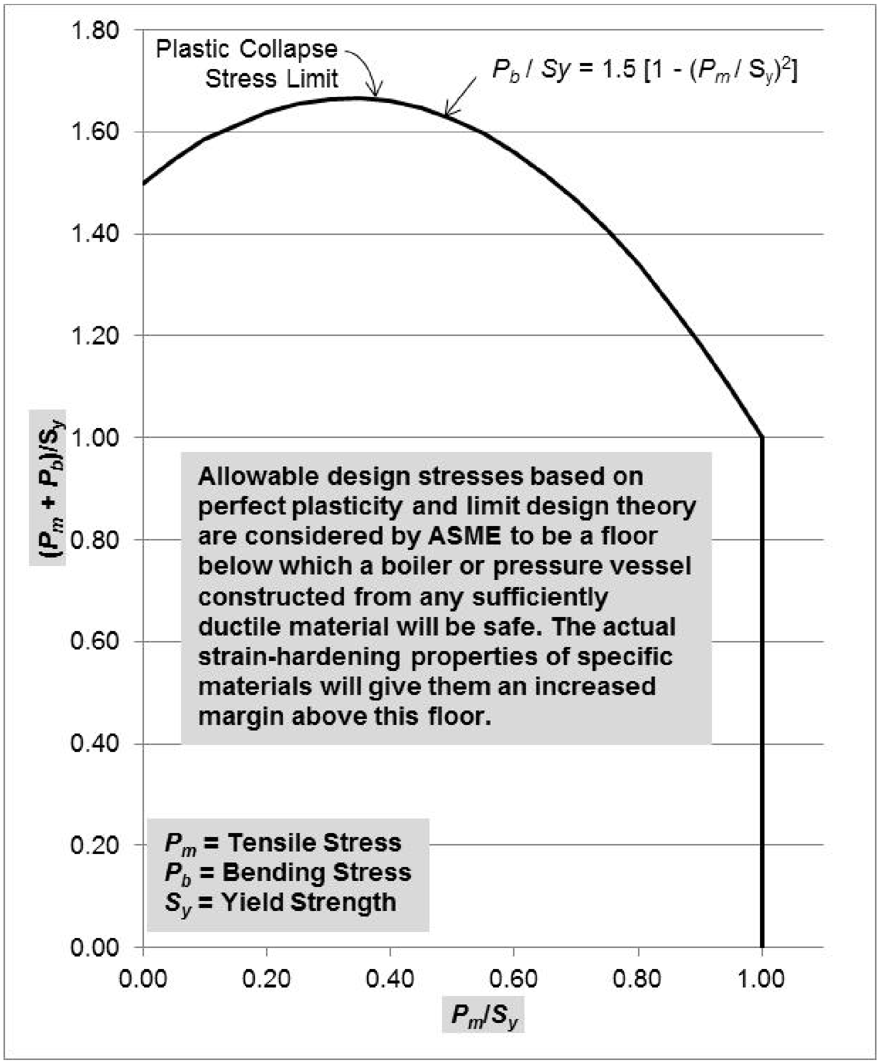

Fig. E.1 Plastic collapse stress limit used as the basis for establishing maximum allowable design stresses specified in the ASME BPVC.

The ASME BPVC places limitations on certain fabrication activities, specifically those involving welding and brazing practices related to boiler and pressure vessel construction, to holders of a valid Certificate of Authorization. However, no organization may assume responsibility for Code construction without having first received from the ASME a Certificate of Authorization to use the Certification Mark and Designators. According to rules specified in the 2021 edition of Section I; Section VIII, Division 1; and Section VIII, Section 2 of ASME BPVC, any Manufacturer holding or applying for a Certificate of Authorization must demonstrate a Quality Control System that meets the requirements of *Conformity Assessment Requirements* in ASME CA-1. This rule was not specified in the 2007 edition of the ASME BPVC because ASME CA-1 was initially published after the 2007 edition was issued.

Rules specified in Section I; Section VIII, Division 1; and Section VIII, Section 2 of ASME BPVC for boiler and pressure vessel fabrication have been revised and updated since the 2007 edition was published. Equivalent safety evaluations of these rule changes are detailed in Tables 9.1 through 9.4, 9.7, and 9.8 of this report. Results of these evaluations show that these rule changes do not violate the fundamental safety assumptions stated or implied in the 2007 edition of the ASME BPVC and therefore provide equivalent safety.

Rules for certification of NDE personnel are specified in Paragraph T-120*(e)* in the 2021 edition of Section V of the ASME BPVC. These rules state that the qualification must be in accordance with the employer's written practice that complies with one of the following documents:

(1) SNT-TC-1A, Personnel Qualification and Certification in Nondestructive Testing (2016 edition); or

(2) ANSI/ASNT CP-189, ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel (2016 edition).

By comparison, Paragraph T-120*(e)* in the 2007 edition of Section V of the ASME BPVC specified the 2001 editions of SNT-TC-1A and ANSI/ASNT CP-189.

Table 6.6 of this report is a crosswalk that maps paragraphs in Section I; Section VIII, Division 1; and Section VIII, Division 2 that provide qualification and certification requirements for NDE personnel to sections referenced in this report where these qualification and certification requirements are examined and explained. Based on equivalent safety evaluations results, these requirement changes do not violate the fundamental safety assumptions stated or implied in the 2007 edition of the ASME BPVC and therefore provide equivalent safety.

E.4 PRESSURE TESTING

Section I and Section VIII, Division 2 in the 2007 and 2021 editions of the ASME BPVC specify limits for maximum primary stresses that occur during pressure testing. These primary stress limits ensure that the boiler or pressure vessel remains below the plastic collapse stress limit. Corresponding primary stress limits are not specified in Section VIII, Division 1 for hydrostatic and pneumatic tests. Instead, any visible permanent distortion that occurs during pressure testing could result in rejection of the pressure vessel by the Inspector.

A comparison of pressure testing requirement specified in the 2007 and 2021 editions of the ASME BPVC is presented in Table E.2 of this report. Except for the minimum hydrostatic pressure test limit specified in the 2007 edition of Section VIII, Division 2 of the ASME BPVC, the pressure testing requirements are the same. In addition, alternative pressure testing and proof testing rules specified in the 2007 and 2021 editions of the ASME BPVC are the same. Based on these comparisons, pressure testing, alternative pressure testing, and proof testing rules specified in the 2021edition of the ASME BPVC do not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.

E.5 OVERPRESSURE PROTECTION

Section XIII – Rules for Overpressure Protection was introduced into the ASME BPVC in the 2021 edition. This new section is intended as an administrative action to incorporate all relief device requirements in a single section of the ASME BPVC and does not provide any new technical requirements beyond those specified in the 2019 edition of the ASME BPVC. Section XIII provides requirements for topics such as design, material, inspection, assembly, testing, and marking for pressure relief valves, rupture disk devices, pin devices, spring-actuated non-reclosing devices, and temperature and pressure relief valves. This standard also covers devices in combination, capacity and flow resistance certification, authorization to use the ASME Certification Mark, installation, and overpressure protection by system design. As a Reference Code, rules specified in Section XIII are only mandatory when referenced from a Construction Code.

Overpressure protection rules specified in the 2007 and 2021 editions of Section I of the ASME BPVC limit the pressure of an operating boiler, except for the steam piping between the boiler and the prime

Table E.2 Comparison of pressure test limits specified in the 2007 and 2021 editions of the ASME BPVC

ASME BPVC and Test Type	Pressure Test and Membrane Stress Limits
Section I Hydrostatic Test (See Sect. 7.1.1.1 and Fig. 7.1 of this report)	2007 – minimum hydrostatic test pressure – 1.5 MAWP 2007 – maximum general membrane stress, P_m, limit – 0.9 S_y* 2021 – minimum hydrostatic test pressure – 1.5 MAWP 2021 – maximum general membrane stress, P_m, limit – 0.9 S_y*
Section VIII, Division 1 Hydrostatic Test (See Sect. 7.1.2.1 and Fig. 7.2 of this report)	2007 – minimum hydrostatic test pressure – 1.3 MAWP 2007 – If the pressure vessel is subjected to visible permanent distortion, the Inspector shall reserve the right to reject the vessel. 2021 – minimum hydrostatic test pressure – 1.3 MAWP 2021 – If the pressure vessel is subjected to visible permanent distortion, the Inspector shall reserve the right to reject the vessel.
Section VIII, Division 1 Pneumatic Test (See Sect. 7.1.2.2 and Fig. 7.3 of this report)	2007 – minimum pneumatic test pressure – 1.1 MAWP 2007 – maximum general membrane stress limit not specified 2021 – minimum pneumatic test pressure – 1.1 MAWP 2021 – maximum general membrane stress limit not specified
Section VIII, Division 2 Hydrostatic Test (See Sect. 7.1.3.1 and Fig. 7.4 of this report)	2007 – minimum hydrostatic test pressure – greater of 1.43 MAWP or 1.25 MAWP(S_T/S) 2007 – maximum general membrane stress, P_m, limit – 0.95 S_y 2021 – minimum hydrostatic test pressure – 1.25 MAWP(S_T/S)† 2021 – maximum general membrane stress, P_m, limit – 0.95 S_y†
Section VIII, Division 2 Pneumatic Test (See Sect. 7.1.3.2 and Fig. 7.5 of this report)	2007 – minimum pneumatic test pressure – 1.15 MAWP(S_T/S) 2007 – maximum general membrane stress, P_m, limit – 0.8 S_y 2021 – minimum pneumatic test pressure – 1.15 MAWP(S_T/S)† 2021 – maximum general membrane stress, P_m, limit – 0.8 S_y†

*No part of the boiler shall be subjected to a general membrane stress greater than 90% of its yield strength (0.2% offset) at test temperature.
†Class 1 and Class 2 Construction

mover, to 1.20 MAWP or less. This overpressure protection limit ensures that the primary membrane stress, P_m, does not exceed $0.80S_y$ (i.e., $1.20/1.50$). The 2021 edition of the ASME BPVC adopts portions of the new Section XIII rules for overpressure protection for capacity certification of pressure relief devices for boilers. Although some requirements in Section I have been transferred to Section XIII, the rules for overpressure protection specified in the 2007 and 2021 editions of Section I of the ASME BPVC are the same.

All Section VIII, Division 1 pressure relief device requirements have been transferred from Paragraphs UG-125 through UG-140 to Section XIII and the remaining Division 1 overpressure protection requirements have been restructured within the new Paragraphs UG-150 through UG-156. Similarly, all Section VIII, Division 2 pressure relief device requirements have been transferred from Part 9 – Pressure Vessel Overpressure Protection to Section XIII and the remaining Division 2 overpressure protection requirements have been restructured within Part 9. However, due to restructuring of paragraphs in the 2021 edition and transferring to Section XIII, a comprehensive equivalent safety evaluation of overpressure protection rules between the 2007 and 2021 edition of Section VIII, Division 1 of the ASME BPVC was not performed.

E.6 OBSERVATIONS

The ASME Boiler and Pressure Vessel Committee's function is to establish rules of safety relating only to pressure integrity which govern the construction of boilers and pressure vessels. However, these rules no longer apply after the boiler or pressure vessel has been placed in service. After a boiler or pressure vessel has been placed in service, degradation of the pressure boundary components can occur. Common types of degradation that can adversely affect the structural integrity of a boiler or pressure vessel include metal loss caused by corrosion or erosion, physical damage caused by cracking or fatigue, and material damage caused by changes in operating conditions or service environments. Detecting and evaluating in-service degradation may be necessary to ensure that the boiler or pressure vessel remains consistent with PHMSA safety objections.

Consensus post-construction standards with requirements for performing in-service inspections and fitness-for-service assessments of boilers and pressure vessels include:

(1) American National Standard NB-23 – National Board Inspection Code
(2) API Standard 510 – Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair, and Alteration
(3) API 579-1/ASME FFS-1, Fitness-for-Service (FFS)

Based on a review of IBR standards in 49 CFR 192, 193, and 195 that apply to boilers and pressure vessels:

- 49 CFR 192 and 193 do not require in service inspections in accordance with American National Standard NB-23 – National Board Inspection Code or API Standard 510.
- 49 CFR 195 incorporates by reference API Standard 510 but not American National Standard NB-23 – National Board Inspection Code.
- 49 CFR 192, 193, and 195 do not require fitness-for-service assessments in accordance with API 579-1/ASME FFS-1.

In-service inspections and fitness-for-service assessments in accordance with these post-construction consensus standards could potentially enhance the safety of boilers and pressure vessels in pipeline facilities because in-service inspection and fitness-for-service assessment results offer a sound basis for decisions to continue to run as is or to alter, repair, monitor, retire or replace the equipment.

1. INTRODUCTION

The U.S. Department of Transportation (DOT) was established by Congress on October 15, 1966 through the *Department of Transportation Act* (Pub. L 89-670). Since then, Congress has enacted various other laws authorizing the Secretary of Transportation to prescribe Federal safety standards for natural gas and hazardous liquid pipelines. Two key statutes provide the framework for the Federal pipeline safety program. The *Natural Gas Pipeline Safety Act of 1968* as amended authorizes DOT to regulate pipeline transportation of natural (flammable, toxic, or corrosive) gas and other gases as well as the transportation and storage of liquefied natural gas (LNG); and the *Hazardous Liquid Pipeline Safety Act of 1979* as amended authorizes DOT to regulate pipeline transportation of hazardous liquids (crude oil, petroleum products, anhydrous ammonia, and carbon dioxide). Federal pipeline safety laws enacted by Congress are listed in Table 1.1 of this report.

Table 1.1 Federal pipeline safety laws

Short title	Public law	Date
Natural Gas Pipeline Safety Act of 1968	90-481	August 12, 1968
Natural Gas Pipeline Safety Act Amendments of 1976	94-477	October 11, 1976
Hazardous Liquid Pipeline Safety Act of 1979	96-129	November 30, 1979
An Act to amend the Natural Gas Pipeline Safety Act of 1968 and the Hazardous Liquid Pipeline Safety Act of 1979	99-516	October 22, 1986
Pipeline Safety Reauthorization Act of 1988	100-561	October 31, 1988
An Act to improve navigational safety and to reduce the hazards to navigation resulting from vessel collisions with pipelines in the marine environment	101-599	November 16, 1990
Pipeline Safety Act of 1992	102-508	October 24, 1992
Accountable Pipeline Safety and Partnership Act of 1996	110-3793	October 12, 1996
Pipeline Safety Improvement Act of 2002	107-355	December 17, 2002
Norman Y. Mineta Research and Special Programs Improvement Act	108-426	November 30, 2004
Pipeline Inspection, Protection, Enforcement, and Safety Act of 2006	109-468	December 29, 2006
Pipeline Safety, Regulatory Certainty, and Job Creation Act of 2011	112-90	January 3, 2012
Protecting Our Infrastructure of Pipelines and Enhancing Safety Act of 2016	114-183	June 22, 2016

1.1 FEDERAL PIPELINE SAFETY STANDARDS

The Pipeline and Hazardous Materials Safety Administration (PHMSA) within DOT is the safety authority responsible for establishing Federal safety standards for natural gas and hazardous liquid pipelines including LNG facilities. These standards are organized and published in Title 49, Parts 190 to 199 of the Code of Federal Regulations (CFR). Titles for 49 CFR Parts 190 to 199 are shown in Table 1.2 of this report.

Table 1.2 Federal Pipeline Safety Standards in Title 49

Part	Title
190	Pipeline safety enforcement and regulatory procedures
191	Transportation of natural and other gas by pipeline; annual reports, incident reports, and safety related condition reports
192	Transportation of natural and other gas by pipeline: minimum Federal safety standards
193	Liquefied natural gas facilities: Federal safety standards
194	Response plans for onshore oil pipelines
195	Transportation of hazardous liquids by pipeline
196	Protection of underground pipelines from excavation activity
198	Regulations for grants to aid State pipeline safety programs
199	Drug and alcohol testing

The Office of Pipeline Safety (OPS), within PHMSA has overall regulatory responsibility for natural gas and hazardous liquid pipelines in the United States that are regulated by PHMSA.

1.2 CODES AND STANDARDS INCORPORATED BY REFERENCE

National consensus codes and standards have been used as the foundation for pipeline safety regulations beginning with the first Federal pipeline safety rules issued in 1970. The *National Technology Transfer and Advancement Act of 1995* (Pub. L. 104-113) [1] directs Federal agencies to use voluntary consensus standards in lieu of government-written standards whenever possible. In compliance with this Act, some or all portions of certain codes and standards are incorporated by reference (IBR) into pipeline safety regulations. Currently, more than 60 IBR codes and standards that are incorporated into 49 CFR Parts 190 to 199. The length of these codes and standards often varies from less than 10 to more than 1,000 pages, and most incorporate secondary references. In addition, many of these codes and standards are copyright protected and not readily accessible except for inspection in the PHMSA office on New Jersey Avenue, SE or at the National Archives and Records Administration in Washington, DC as stated in §193.2013(b) or through purchase from the respective standards-developing organization.

To the extent practicable, PHMSA is authorized and responsible for ensuring that pipeline safety regulations are consistent with safety requirements specified in IBR consensus codes and standards. Rather than promulgating pipeline safety regulations for boilers; pressure vessels; and the production, storage, and handling of LNG, PHMSA incorporates applicable rules published by American Society of Mechanical Engineers (ASME) International, the American Petroleum Institute (API), and the National Fire Protection Association (NFPA) into 49 CFR Parts 192, 193, and 195 through the IBR process. By incorporating specific editions of codes and standards into Federal pipeline safety regulations, these codes and standards have the full force of law.

Table 1.3 of this report lists titles and editions of IBR codes and standards for boilers and pressure vessels published by ASME International. Rules and requirements in these IBR codes and standards are:

- applicable to boilers and pressure vessels in pipeline facilities within the scope of 49 CFR Part 192, and
- approved for the specific paragraphs identified in §192.7.

Table 1.3 ASME BPVC references incorporated in 49 CFR Part 192

49 CFR Paragraph	Reference	IBR approved for
§192.7(c)(7)	ASME Boiler & Pressure Vessel Code, Section I: "Rules for Construction of Power Boilers 2007," 2007 edition, July 1, 2007, (ASME BPVC, Section I)	§192.153(b)
§192.7(c)(8)	ASME Boiler & Pressure Vessel Code, Section VIII, Division 1: "Rules for Construction of Pressure Vessels," 2007 edition, July 1, 2007, (ASME BPVC, Section VIII, Division 1)	§§192.153(a), (b), (d); and 192.165(b)
§192.7(c)(9)	ASME Boiler & Pressure Vessel Code, Section VIII, Division 2: "Alternate Rules, Rules for Construction of Pressure Vessels," 2007 edition, July 1, 2007, (ASME BPVC, Section VIII, Division 2)	§§192.153(b), (d); and 192.165(b)
§192.7(c)(10)	ASME Boiler & Pressure Vessel Code, Section IX: "Qualification Standards for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operations," 2007 edition, July 1, 2007, (ASME BPVC, Section IX)	§§192.225(a); 192.227(a); and Item II, Appendix B to Part 192

Table 1.4 of this report lists titles and editions of IBR codes and standards for boilers and pressure vessels published by ASME International and NFPA. Rules and requirements in these IBR codes and standards are:

- applicable to boilers and pressure vessels in liquefied natural gas facilities within the scope of 49 CFR Part 193, and
- approved for the specific paragraphs identified in §193.2013.

Table 1.4 ASME BPVC and NFPA references incorporated in 49 CFR Part 193

49 CFR Paragraph	Reference	IBR approved for
§193.2013(e)(1)	ASME Boiler & Pressure Vessel Code, Section VIII, Division 1: "Rules for Construction of Pressure Vessels," 2007 edition, July 1, 2007, (ASME BPVC, Section VIII, Division 1)	§ 193.2321(a) (See Note 1)
§193.2013(g)(1)	NFPA–59A (2001), "Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)," (NFPA 59A–2001) [NFPA–59A (2001) incorporates by reference the ASME BPVC, 1992 Edition. See Note 2.]	§§ 193.2019(a), 193.2051, 193.2057, 193.2059 introductory text and (c), 193.2101(a), 193.2301, 193.2303, 193.2401, 193.2521, 193.2639(a), and 193.2801
§193.2013(g)(2)	NFPA 59A (2006), "Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)," 2006 edition, approved August 18, 2005, (NFPA–59A–2006) [NFPA–59A (2006) incorporates by reference the ASME BPVC, 2004 Edition. See Note 3.]	§§ 193.2101(b) and 193.2321(b)

Notes:

1. Butt welds in metal shells of storage tanks with internal design pressure above 15 psig must be nondestructively examined in accordance with rules specified in Section VIII, Division 1 of the ASME BPVC (incorporated by reference, see §193.2013) except that 100 percent of welds that are both longitudinal (or meridional) and circumferential (or latitudinal) of hydraulic load bearing shells with curved surfaces that are subject to

cryogenic temperatures must be nondestructively examined in accordance with rules specified in Section VIII, Division 1 of the ASME BPVC.

2. Chapter 12 of NFPA 59A-2001 lists documents or portions thereof that are referenced within this standard are mandatory requirements and shall be considered part of the requirements of this standard. This list includes the 1992 edition of the ASME BPVC, including Addenda and applicable Code Interpretation Cases.
3. Chapter 2 of NFPA 59A-2006 lists documents or portions thereof that are referenced within this standard are mandatory requirements and shall be considered part of the requirements of this standard. This list includes the 2004 edition of the ASME BPVC.

Table 1.5 of this report lists titles and editions of IBR codes and standards for boilers and pressure vessels published by ASME International and API. Rules and requirements in these IBR codes and standards are:

- applicable to boilers and pressure vessels in hazardous liquids by pipeline facilities within the scope of 49 CFR Part 195, and
- approved for the specific paragraphs identified in §195.3.

Table 1.5 ASME BPVC and API references incorporated in 49 CFR Part 195

49 CFR Paragraph	Reference	IBR approved for
§195.3(b)(16)	API Standard 510, ‘‘Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair, and Alteration,’’ 9th edition, June 2006, (API Std 510)	§195.205(b) and 195.432(c)
§195.3(c)(5)	ASME Boiler & Pressure Vessel Code, Section VIII, Division 1: “Rules for Construction of Pressure Vessels,” 2007 edition, July 1, 2007, (ASME BPVC, Section VIII, Division 1)	§§195.124 and 195.307(e)
§195.3(c)(6)	ASME Boiler & Pressure Vessel Code, Section VIII, Division 2: “Alternate Rules, Rules for Construction of Pressure Vessels,” 2007 edition, July 1, 2007, (ASME BPVC, Section VIII, Division 2)	§195.307(e)
§195.3(c)(7)	ASME Boiler & Pressure Vessel Code, Section IX: “Qualification Standards for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operations,” 2007 edition, July 1, 2007, (ASME BPVC, Section IX)	§195.222(a)

1.3 COMPLIANCE WITH IBR CODES AND STANDARDS

In general, standards-developing organizations update and revise their codes and standards on a 2 to 5-year schedule. As an example, new editions of the ASME BPVC are published on July 1 of odd numbered years (i.e., July 1, 2019, July 1, 2021, etc.). This means that beginning on July 1, 2021, a new boilers or pressure vessel can only be assigned a Certification Mark with the appropriate Designator in accordance with rules specified in the 2021 edition of ASME BPVC Section I, Section VIII, Division 1, or Section VIII, Section 2, as applicable.

Until January 31, 2013, no organization was permitted to assume responsibility for Code construction without having first received from the ASME a Certificate of Authorization to use applicable Code symbol stamps. However, after January 31, 2013, no organization was permitted to assume responsibility for Code construction without having first received from the ASME a Certificate of Authorization to use the Certification Mark and Designators. A Certification Mark is an ASME symbol identifying a product as meeting Code requirements and a Certification Designator (Designator) is the symbol used in conjunction with the Certification Mark for the scope of activity described in a Manufacturer’s Certificate of Authorization. Any Manufacturer holding or applying for a Certificate of Authorization must demonstrate a Quality Control System that meets the requirements of *Conformity Assessment Requirements* in ASME CA-1 [2].

Application of a Certification Mark or a Code symbol stamp for a boiler or pressure vessel constructed to a superseded edition of the ASME BPVC is not permitted. Therefore, compliance with PHMSA regulations by pipeline operators may involve satisfying requirements specified in an IBR code or standard that are either obsolete or no longer applicable.

1.3.1 Special Permit Applications

One way for a pipeline operator to address a potential non-compliance issues with a PHMSA regulations is to submit a special permit application to PHMSA in accordance with requirements specified in §190.341. A special permit is an order by which PHMSA waives compliance with one or more Federal pipeline safety regulations.

Special permit applications must contain the information described in §190.341(c) including the following:

- an explanation of the unique circumstances that the applicant believes make the applicability of that regulation or standard (or portion thereof) unnecessary or inappropriate for its facility.
- a description of any measures or activities the applicant proposes to undertake as an alternative to compliance with the relevant regulation, including an explanation of how such measures will mitigate any safety or environmental risks.

Upon receipt of a special permit application, PHMSA is required to provide notice to the public of its intent to consider the application and invite comment. In addition, PHMSA may consult with other Federal agencies before granting or denying an application on matters that PHMSA believes may have significance for proceedings under their areas of responsibility. Review of a special permit by PHMSA is estimated at 6 to 12 months and possibly longer, and issuance of a special permit cannot be guaranteed. In many cases, the term of a special permit is five years, which requires the special permits to be renewed before the five-year period expires. The policy regarding the termination period of a special permit requires review by PHMSA on a case-by-case basis.

1.3.2 Safety Equivalency Technical Documentation

Operators of LNG facilities regulated under 49 CFR Part 193 have an additional option for requesting PHMSA to waive compliance with one or more Federal pipeline safety regulations. This option, which is described in NFPA 59A-2001, Sect. 1.2, Paragraph 3.4.2, and Paragraph 12.1.2.4, involves the operator submitting safety equivalency technical documentation to PHMSA to consider as the Jurisdiction Having Authority (AHJ). The equivalency provision in Sect. 1.2 of NFPA 59A-2001 is explained as follow.

> ***1.2 Equivalency.*** *Nothing in this standard is intended to prevent the use of systems, methods, or devices of equivalent or superior quality, strength, fire resistance, effectiveness, durability, and safety over those prescribed by this standard. Technical documentation shall be submitted to the authority having jurisdiction to demonstrate equivalency. The system, method, or device shall be approved for the intended purpose by the authority having jurisdiction.*

In addition, NFPA 59A-2001, Paragraph 3.4.2 states the following.

> *Boilers shall be designed and fabricated in accordance with the ASME Boiler and Pressure Vessel Code, Section I, or CSA Standard B 51, Boiler, Pressure Vessel and Pressure Piping Code, and pressure vessels shall be designed and fabricated in accordance with the ASME Boiler*

and Pressure Vessel Code, Section VIII, Division 1 or Division 2, or CSA Standard B 51, Boiler, Pressure Vessel and Pressure Piping Code and shall be Code stamped. (Note: As discussed in Sect. 1.3 of this report, the term Code stamp was replaced with the term Certification Mark on January 31, 2013.)

The referenced edition of the ASME BPVC listed in NFPA 59A-2001, Paragraph 12.1.2.4 is:

ASME Boiler and Pressure Vessel Code, 1992 edition, including Addenda and applicable Code Interpretation Cases.

To receive approval from PHMSA for "Equivalency", the LNG facility operator must demonstrate that the proposed systems, methods, or devices are either equivalent or have superior quality, strength, fire resistance, effectiveness, durability, and safety over those required in 49 CFR Part 193. Based on results of its equivalency evaluation, PHMSA may issue a letter to the LNG facility operator stating no objections to the equivalency framework. This "no objection" letter may include statements intended to clarify actions proposed by the LNG facility operator for ensuring equivalent safety [3].

1.4 RATIONALE AND JUSTIFICATION FOR EQUIVALENT SAFETY EVALUATIONS

Rationale and justification for concluding that the rules and requirements specified in IBR editions of the ASME BPVC to later editions of the ASME BPVC provide equal or greater safety for boilers and pressure vessels in pipeline facilities are documented in two reports. Safety equivalency evaluation results presented in these two reports were determined using a combination of quantitative and qualitative as discussed in Sects. 1.4.1 and 1.4.2 of this report. Rules and requirements specified in the 2007 edition of the ASME BPVC that are the same as those in the 2021 edition are considered to provide equivalent safety.

The first report titled *ASME Boiler and Pressure Vessel Code Evaluation and Equivalence Study for Liquefied Natural Gas Facilities* [4] was prepared in 2017 to address risks associated with LNG facilities within the scope of 49 CFR Part 193. For this study, the safety baseline for comparison is the 1992 edition of the ASME BPVC. This report concludes that the rules and requirements specified in Section I; Section VIII, Division 1; and Section VIII, Division 2 in the 2015 edition of the ASME BPVC are equivalent in safety to the corresponding rules and requirements specified in Section I; Section VIII, Division 1; and Section VIII, Division 2 in the 1992 edition of the ASME BPVC. Equivalency evaluation results presented in this report focus primarily on materials; design including failure modes, strength theories, and principles of limit design theory; fabrication and inspection including nondestructive examinations; pressure testing; and overpressure protection.

This second report uses a similar technical approach to conclude that the rules and requirements specified in the 2007 IBR edition of the ASME BPVC provide equal or greater safety for boilers and pressure vessels in pipeline facilities compared to corresponding rules and requirements specified in the 2021 editions of the ASME BPVC. The safety baseline for comparison is the 2007 edition of the ASME BPVC which PHMSA considers the minimum acceptable level of safety for boilers and pressure vessels for pipeline facilities. Equivalency evaluation results presented in this report are based on comparisons of rules and requirements specified in the ASME BPVC sections and editions of the Construction and References Codes listed in Table 1.6 of this report.

1.4.1 Safety Equivalency Evaluations Using Quantitative Comparative Analysis

Safety equivalency evaluations based on quantitative comparative analysis results can be relatively straight forward as illustrated in the following equivalency evaluation of requirements provided in

Section VIII, Division 1, Paragraph UG-101 – Proof Tests to Establish Maximum Allowable Working Pressure in the ASME BPVC.

Table 1.6 Basis for equivalency evaluations

ASME BPVC Construction Code	ASME BPVC Reference Code
Section I – Rules for Construction of Power Boilers, 2007 vs 2021 Editions	Section II – Materials, 2007 vs 2021 Editions
Section VIII. Division 1 – Rules for Construction of Pressure Vessels, 2007 vs 2021 Editions	Section V – Nondestructive Examination, 2007 vs 2021 Editions
Section VIII. Division 2 – Alternative Rules – Rules for Construction of Pressure Vessels, 2007 vs 2021 Editions	Section IX – Qualification Standard for Welding, Brazing, and Fusing Procedures; Welders; Brazers; and Welding, Brazing, and Fusing Operators, 2007 vs 2021 Editions
	Section XIII – Rules for Overpressure Protection, 2021 Edition (Note: Section XIII was introduced into the ASME BPVC in the 2021 edition.)

Notes:

1. Construction Code – provides rules for materials, design, fabrication, examination, inspection, testing, certification, and pressure relief. Construction Codes refer to Reference Codes.
2. Reference Code – provides standards for materials, welding and brazing procedures and qualifications, nondestructive examination, and overpressure protection that are referenced by the Construction Codes.

Paragraphs UG-101*(l)(2)*, UG-101*(m)(2)*, UG-101*(n)(4)*, and UG-101*(o)(5)* in the 1992 edition of Section VIII, Division 1 of ASME BPVC include the term 'formulas.' Whereas corresponding text in Paragraphs UG-101*(l)(2)*, UG-101*(m)(2)*, UG-101*(n)(4)*, and UG-101*(o)(5)* in the 2021 edition of Section VIII, Division 1 of ASME BPVC include the term 'equations.' In addition, both editions refer to identical mathematical relations. Therefore, the text changes from 'formulas' to 'equations' do not have an adverse impact on the safety equivalency of pressure vessels and pressure vessel parts designed and fabricated in accordance with rules specified in the 2021 edition of Section VIII, Division 1 of the ASME BPVC compared to pressure vessels and pressure vessel parts designed and fabricated in accordance with rules specified in the 1992 edition of Section VIII, Division 1 of the ASME BPVC.

Although comparisons such as this are elementary, a word-by-word or sentence-by-sentence comparison of text in the IBR edition of the ASME BPVC to a later edition of the ASME BPVC is not always feasible. This is especially true when text in a particular paragraph in the later edition of the ASME BPVC has been reorganized, redesignated, deleted, added, or moved relative to the corresponding text in the IBR edition of the ASME BPVC. For example, the 2007 edition of Section VIII, Division 2 of the ASME BPVC was completely rewritten and reformatted making a direct comparison of text in the 1992 edition of the ASME BPVC and the 2007 and subsequent editions of the ASME BPVC impossible. Direct comparisons of rules and requirements prescribed in the 2007 and 2021 editions of the ASME BPVC are more straightforward because the paragraph numbers are typically consistent, the sentence structure is similar, and the figure and table formats are alike.

1.4.2 Safety Equivalency Evaluations Using Qualitative Comparative Analysis

Safety equivalency evaluations based on qualitative comparative analysis results often involve an equivalency evaluation based on technical rationale that involves engineering judgement to ensure that the safety objectives of the later edition of the ASME BPVC fulfill the intended safety objectives of the IBR editions. As an example, consider the differences in hydrostatic pressure testing requirements specified in the 1992 and 2021 editions of Section VIII, Division 1 of the ASME BPVC where:

- **Paragraph UG-100 – Standard Hydro Test** in the 1992 edition of Section VIII, Division 1 of the ASME BPVC states that vessels designed for internal pressure shall be subjected to a hydrostatic test pressure which at every point in the vessel is at least equal to 1.5 times the maximum allowable working pressure to be marked on the pressure vessel multiplied by the lowest ratio (for the materials of which the vessel is constructed) of the stress value *S* for the test temperature on the vessel to the stress value *S* for the design temperature.
- **Paragraph UG-99 – Standard Hydro Test** in the 2021 edition of Section VIII, Division 1 of the ASME BPVC states:
    1. **Paragraph UG-99*(b)*** states that vessels designed for internal pressure shall be subjected to a hydrostatic test pressure that at every point in the vessel is at least equal to 1.3 times the maximum allowable working pressure multiplied by the lowest stress ratio (LSR) for the materials of which the vessel is constructed.
    2. **Paragraph UG-99*(f)*** adds vacuum test requirements for pressure vessels designed for vacuum service. These requirements states that the vacuum test shall be conducted at the lowest value of specified absolute internal design pressure and that the leak test shall be performed following a written procedure complying with the applicable technical requirements of Section V, Article 10 for the leak test method and technique specified by the user. Leak testing personnel shall be qualified and certified as required by Section V, Article 1 – General Requirements, T-120*(e)*. (See Sect. 6.3.1 of this report.)

Evaluating the safety significance of the difference between these hydrostatic test pressure rules requires an understanding of the purpose and underlying maximum allowable design stress limits and the plastic collapse stress limits used as the basis for these hydrostatic test pressure requirements. Hydrostatic tests are performed after fabrication is completed primarily to verify the leak tight integrity of the pressure boundary but also to identify gross deformations or anomalies that may indicate design errors, material deficiencies, or weld defects. Further discussion about hydrostatic pressure testing is provided in Sect. 7.1 of this report.

This report documents the technical rationale used to determine whether boilers and pressure vessels designed and fabricated in accordance with rules and requirements specified in the 2021 edition of the ASME BPVC are as safe as boilers and pressure vessels designed and fabricated in accordance with rules and requirements specified in the 2007 edition of the ASME BPVC. The basis for the technical rationale was established by a team of Subject Matter Experts (SMEs) from the Oak Ridge National Laboratory (ORNL) through reviews of ASME BPVC rules and consideration of information presented in open-source, publicly available reference documents.

The scope of this report is limited to a comparison of rules and requirements specified in the 2007 and 2021 editions of the ASME BPVC because differences among corresponding rules and requirements specified in the 2007 and 2021 editions of the ASME BPVC could potentially have an adverse effect on the safety of boilers and pressure vessels. The safety baseline for comparison is the 2007 edition of the ASME BPVC which PHMSA considers the minimum acceptable level of safety for boilers and pressure vessels.

1.5 PURPOSE AND NEED FOR SAFETY EQUIVALENCY EVALUATIONS

Before PHMSA can revise or update Federal pipeline safety regulations using the rule making procedures defined in 49 CFR Part 190, it must ensure that all proposed changes result in conditions that are at least as safe as those provided by existing regulations. These safety equivalency determinations are based on either qualitative or quantitative comparative analysis results in which the safety consequences and potential benefits of the changes are assessed and the technical rationale for determining whether the proposed changes do, or do not, result in equivalent safety are documented. Significant changes to ASME BPVC requirements that have been approved since the 2019 was published are reported in a document titled: *Summary of Significant Changes in the 2021 ASME Boiler and Pressure Vessel Code, Sections VIII, XII, II, V, and IX* [5].

The safety equivalency evaluations presented in the report titled: *ASME Boiler and Pressure Vessel Code Evaluation and Equivalence Study for Liquefied Natural Gas Facilities* [4] and this report are intended to provide PHMSA with information needed to:

- determine if the rule and requirement changes in later editions up to and including the 2021 edition of the ASME BPVC result in conditions that are at least as safe as those provided in the IBR editions of the ASME BPVC.
- verify that new boilers and pressure vessels for LNG facilities comply with NFPA 59A (2001 edition) as required in §193.2013(g)(1).

2. ASME BPVC SCOPE AND REVISION PROCESS

The ASME BPVC is a consensus standard that specifies requirements for design and fabrication of boilers and pressure vessels. The 2021 edition of the ASME BPVC, which applicable from July 1, 2021 through June 30, 2023, is organized into the various sections listed in Table 2.1.

Table 2.1 Section titles in the 2021 edition of the ASME Boiler and Pressure Vessel Code

Section	Title
I	Rules for Construction of Power Boilers (See Note 1)
II	Materials (See Note 2)
III	Rules for Construction of Nuclear Facility Components (See Note 1)
IV	Rules for Construction of Heating Boilers (See Note 1)
V	Nondestructive Examination (See Note 2)
VI	Recommended Rules for the Care and Operation of Heating Boilers
VII	Recommended Guidelines for the Care of Power Boilers
VIII, Div. 1	Rules for Construction of Pressure Vessels (See Note 1)
VIII, Div. 2	Rules for Construction of Pressure Vessels – Alternative Rules (See Note 1)
VIII, Div. 3	Rules for Construction of Pressure Vessels – Alternative Rules for Construction of High Pressure Vessels (See Note 1)
IX	Qualification Standard for Welding, Brazing, and Fusing Procedures; Welders; Brazers; and Welding, Brazing, and Fusing Operators (See Note 2)
X	Fiber-Reinforced Plastic Pressure Vessels (See Note 1)
XI	Rules for Inservice Inspection of Nuclear Power Plant Components
XII	Rules for Construction and Continued Service of Transport Tanks (See Notes 1)
XIII	Rules for Overpressure Protection (See Note 2)

Notes:

1. Construction Code – provides rules for materials, design, fabrication, examination, inspection, testing, certification, and pressure relief. Construction Codes refer to Reference Codes.
2. Reference Code – provides standards for materials, welding and brazing procedures and qualifications, and nondestructive examination that are referenced by the Construction Codes.

Various ASME Boiler and Pressure Vessel Committees, which are referred to individually or collectively as the ASME Boiler and Pressure Vessel Committee, are responsible for formulating rules for construction of boilers, pressure vessels, transport tanks, and nuclear components, and the in-service inspection of nuclear components and transport tanks. In this context, the word “construction” is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

The ASME Boiler and Pressure Vessel Committee meets regularly to consider revisions to existing rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Committee has the authority to provide official Code Interpretations of the ASME BPVC. Actions of the Committee become effective only after confirmation by ballot of the Committee and approval by ASME. After public review and final approval by ASME, revisions are published at regular intervals in editions of the ASME BPVC. The terms "Code Case" and "Code Interpretations" are defined as follows in the 2021 edition of Section VIII, Division 2 of the ASME BPVC.

> *Code Cases represent alternatives or additions to existing Code rules. Code Cases are written as a question and reply and are usually intended to be incorporated into the Code at a later date. When used, Code Cases prescribe mandatory requirements in the same sense as the text of the Code. However, users are cautioned that not all jurisdictions or owners automatically accept Code Cases. The most common applications for Code Cases are:*
>
> - *to permit early implementation of an approved Code revision based on an urgent need*
> - *to permit the use of a new material for Code construction*
> - *to gain experience with new materials or alternative rules prior to incorporation directly into the Code*
>
> *Code Interpretations provide clarification of the meaning of existing rules in the Code, and are also presented in question and reply format. Interpretations do not introduce new requirements. In cases where existing Code text does not fully convey the meaning that was intended, and revision of the rules is required to support an interpretation, an Intent Interpretation will be issued and the Code will be revised.*

The ASME Boiler and Pressure Vessel Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with ASME BPVC rules and demonstrating compliance with Code equations when such equations are mandatory. The ASME BPVC neither requires nor prohibits the use of computers for the design or analysis of components constructed to the requirements of the ASME BPVC. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and the application of these programs to their design. In addition, the ASME BPVC does not contain rules to cover all details of design and fabrication. Where complete details are not given, it is intended that the manufacturer, subject to the acceptance of the Authorized Inspector, provide details of design and fabrication that will be as safe as otherwise provided by the rules in the ASME BPVC.

After revisions to the ASME BPVC are approved by ASME, they may be used beginning with the date of issuance. In most cases, revisions become mandatory 6 months after the date of issuance. Errata to the ASME BPVC are posted on the ASME web site to provide corrections to incorrectly published items, or to correct typographical or grammatical errors. Such Errata must be used on the date posted.

The ASME BPVC edition used for construction of a boiler or pressure vessel must be either the edition that is mandatory on the date the boiler or pressure vessel is contracted for by the manufacturer, or a published edition issued by ASME prior to the contract date, which is not yet mandatory. Even though construction of a boiler or a pressure vessel to a superseded edition of the ASME BPVC may be possible, the Authorized Inspector will not issue approval to the Manufacturer to apply the Certification Mark.

Some or all requirements in the ASME BPVC has been adopted into law by 50 states and many municipalities in the United States. The specific sections and editions of the ASME BPVC incorporated by reference in 49 CFR Part 192, 193 and 195 are listed in Tables 1.3, 1.4, and 1.5, respectively.

2.1 SECTION I – RULES FOR CONSTRUCTION OF POWER BOILERS

Section I of the ASME BPVC provides requirements for construction of power boilers, electric boilers, miniature boilers, high-temperature water boilers, heat recovery steam generators, solar receiver steam generators, certain fired pressure vessels, and liquid phase thermal fluid heaters to be used in stationary service and includes those power boilers used in locomotive, portable, and traction service. Design and fabrication rules specified in Section I apply to the boiler proper and to the boiler external piping. Superheaters, economizers, and other pressure parts connected directly to the boiler without intervening valves are also considered parts of the boiler proper, and their construction must conform to Section I rules. The Preamble for the 2021 edition of Section I of the ASME BPVC states that boiler external piping must be considered as that piping which begins where the boiler proper or isolable superheater or isolable economizer terminates at:

(a) the first circumferential joint for welding end connections; or
(b) the face of the first flange in bolted flanged connections; or
(c) the first threaded joint in that type of connection; and which extends up to and including the valve or valves required by Section I of the ASME BPVC.

According to requirements in the 2021 edition of Section I, Paragraph PG-105 of the ASME BPVC, no organization may assume responsibility for Code construction without having first received from the ASME a Certificate of Authorization to use the Certification Mark and Designators. The Designators used with Certification Marks for Section I construction are defined as follows.

S — power boiler Designator
M — miniature boiler Designator
E — electric boiler Designator
A — boiler assembly Designator
PP — pressure piping Designator
V — boiler pressure relief valve Designator
PRT — fabricated parts Designator

Rule changes to Paragraph PG-105 from the 2007 edition to the 2021 edition of Section I of the ASME BPVC require organizations that assume responsibility for Code construction to comply with ASME CA-1 [2].

PG-105.2 Application for Certificate of Authorization states: Any organization desiring a Certificate of Authorization shall apply to the ASME in accordance with the certification process of ASME CA-1. Authorization to use Certification Marks may be granted, renewed, suspended, or withdrawn as specified in ASME CA-1.

PG-105.3 Designated Oversight states: The Manufacturer or Assembler shall comply with the requirements of ASME CA-1 for Designated Oversight by use of an Authorized Inspection Agency or Certified Individual, as applicable.

PG-105.4 Quality Control System states: Any Manufacturer or Assembler holding or applying for a Certificate of Authorization shall demonstrate a quality program that meets the requirements of ASME CA-1 and establishes that all Code requirements including material, design, fabrication, examination (by the Manufacturer), and inspection for boilers and boiler parts (by the Authorized Inspector) will be met. The quality control system shall be in accordance with the requirements of A-301 and A-302. (See Sect. 5.6.1 of this report.)

PG-105.5 Code Construction Before Receipt of Certificate of Authorization states: When used to demonstrate his quality control system, a Manufacturer may start fabricating Code items before receipt of a Certificate of Authorization to use a Certification Mark under the conditions specified in ASME CA-1.

ASME Code Certification (including Data Forms and stamping the Certification Mark with appropriate Designator) and inspection by the Authorized Inspector, when required by Section I, are required for the boiler proper and the boiler external piping. Paragraph PG-91 – Qualification of Inspectors in the 2021 edition of Section I of the ASME BPVC states that the inspection required by this Section shall be by an Inspector employed by an ASME accredited Authorized Inspection Agency. These Inspectors shall have been qualified in accordance with ASME QAI-1, *Qualifications for Authorized Inspection*. Certification Mark is an ASME symbol identifying a product as meeting Code requirements, and a Certification Designator (Designator) is the symbol used in conjunction with the Certification Mark for the scope of activity described in a Manufacturer's Certificate of Authorization. Each boiler, superheater, waterwall, economizer, or boiler part to which a Certification Mark is to be applied shall be fabricated by a Manufacturer who is in possession of a Certificate of Authorization to use the Certification Mark with appropriate Designator. In addition to the applicable Designator, the boiler must also be stamped to show the maximum allowable working pressure (MAWP) when built and the other information specified in Section I, PG-106.4.1 in the 2021 edition of the ASME BPVC.

According to requirements in Section I, PG-3 in the 2021 edition of the ASME BPVC, the Manufacturer is responsible for establishing the effective Code Edition, Addenda, and Code Cases for boilers and replacement parts in accordance with rules specified in Mandatory Appendix VI. Specific editions of standards referenced in Section I are shown in Table A-360. Mandatory Appendix VI states that after Code revisions are approved by ASME, they may be used beginning with the date of issuance shown on the Code and revisions become mandatory 6 months after the date of issuance. Code Cases are permissible and may be used beginning with the date of approval by ASME. However, only Code Cases that are specifically identified as being applicable to this Section may be used.

Mandatory Appendix III in the 2021 edition of Section I of the ASME BPVC provides rules for reapplication of the Certification Mark but only when the conditions defined in Paragraph III-2 apply and only to restore evidence of original compliance with ASME Section I requirements.

2.2 SECTION VIII, DIVISION 1 – RULES FOR CONSTRUCTION OF PRESSURE VESSELS

Section VIII, Division 1 contains mandatory requirements, specific prohibitions, and nonmandatory guidance for pressure vessel materials, design, fabrication, examination, inspection, testing, certification, and pressure relief for pressure vessels that operate at either internal or external pressures. This pressure may be obtained from an external source, or by the application of heat from a direct or indirect source, or any combination thereof. Such pressure vessels may be fabricated by welding, forging, or brazing.

Paragraph UG-1*(c)(1)* in the 2021 edition of Section VIII, Division 1 of the ASME BPVC states:

> *The scope of this Division has been established to identify the components and parameters considered in formulating the rules given in this Division. Laws or regulations issued by municipality, state, provincial, Federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the Code rules, in whole or in part, within their jurisdiction. Those laws or regulations may require the use of this Division of the Code for vessels or components not considered to be within its Scope. These laws or regulations should be reviewed to determine size or service limitations of the coverage which may be different or more restrictive than those given here.*

Rules and requirements in Section VIII, Division 1 of the ASME BPVC are divided into three Subsections, Mandatory Appendices, and Nonmandatory Appendices. Although Section VIII, Division 1 does not address all aspects of pressure vessel materials, design, fabrication, examination, inspection, testing, certification, and pressure relief, those aspects which are not specifically addressed should not be considered prohibited. Engineering judgment must be consistent with the philosophy of Division 1, and such judgments must never be used to overrule mandatory requirements or specific prohibitions of Division 1.

Pressure vessels certified in accordance with Section VIII, Division 1 requirements must be marked with the official Certification Mark U, UM, or PRT Designator, as appropriate, and the other required information as described in Paragraph UG-116 in the 2021 edition of Section VIII, Division 1 of the ASME BPVC which includes the MAWP (internal or external) and the MDMT.

2.3 SECTION VIII, DIVISION 2 – ALTERNATIVE RULES FOR CONSTRUCTION OF PRESSURE VESSELS

Section VIII, Division 2 of the ASME BPVC provides materials, design, and nondestructive examination requirements that are more rigorous than those provided in Section VIII, Division 1; however, higher design stress intensity values are permitted. The scope of the 2021 edition of Section VIII, Division 2 of the ASME BPVC is defined in Part 1 – General Requirements, Paragraph 1.2 – Scope.
Paragraphs 1.2.1.1 and 1.2.1.2 state:

> *In the scope of this division, pressure vessels are containers for the containment of pressure, either internal or external. This pressure may be obtained from an external source or by the application of heat from a direct or indirect source as a result of a process, or any combination thereof.*
>
> *Vessels with an internal or external design pressure not exceeding 103 kPa (15 psi) and multichambered vessels of which the design pressure on the common elements does not exceed 103 kPa (15 psi) were not considered when the rules of this Division were developed and are not considered within the scope.*

Paragraph 1.2.1.4 further states:

> *The scope of this Division has been established to identify components and parameters considered in formulating the rules given in this Division. Laws or regulations issued by municipality, state, provincial, federal, or other enforcement or regulatory bodies having jurisdiction at the location of an installation establish the mandatory applicability of the Code rules, in whole or in part, within the jurisdiction. Those laws or regulations may require the use of this Division of the Code for vessels or components not considered to be within its scope. These laws or regulations should be reviewed to determine size or service limitations of the coverage which may be different or more restrictive than those given here.*

Part 1, Paragraph 1.2 – Scope, Paragraphs 1.2.2 through 1.2.7 in 2021 edition of Section VIII, Division 2 define:

- additional requirements for high pressure vessels
- geometric scope of this Division
- classifications outside the scope of this Division
- combination units
- field assembly of vessels
- overpressure protection

The rules of Division 2 may be used for the construction of pressure vessels designated as either Class 1 or Class 2 defined as follows.

- A Class 1 Vessel is a vessel that is designed using the allowable stresses from Section II, Part D, Subpart 1, Table 2A or Table 2B.

- A Class 2 Vessel is a vessel that is designed using the allowable stresses from Section II, Part D, Subpart 1, Table 5A or Table 5B.

Additional general requirements are provided in Part 1, Paragraphs 1.3 through 1.7. Paragraph 1.3 identifies standards referenced by Division 2. These referenced standards are listed in Table 1.1. Paragraph 1.4 states that either U.S. Customary, SI, or any local customary units may be used to demonstrate compliance with requirements of this edition related to materials, fabrication, examination, inspection, testing, certification, and overpressure protection. Standard units for use in equations are listed in Table 1.2. Tolerance requirements are provided in Paragraph 1.5 which states that the Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal, and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practices as determined by the designer. Requirements for technical inquiries are provided in Paragraph 1.6 which states a procedure for submittal of Technical Inquiries to the ASME Boiler and Pressure Vessel Code Committee is contained in the front matter. Table 1.1 Year of Acceptable Edition of Referenced Standards in This Division and Table 1.2 Standard Units for Use in Equations are included in Paragraph 1.7.

Responsibilities and duties for Users, Manufacturers, and Authorized Inspectors are provides in Part 2 – Responsibilities and Duties of the 2021 edition of Section VIII, Division 2 of the ASME BPVC. According to Part 2, Paragraph 2.2, the User, or an agent acting on behalf of the User is responsibility for providing a User’s Design Specification for each pressure vessel to be constructed in accordance with Division 2. The User’s Design Specification contains sufficient detail to provide a complete basis for design and construction in accordance with Division 2. The User is also responsible for specifying the effective Code edition and vessel class to be used for construction.

Part 2 – Responsibilities and Duties, Paragraph 2.3 states that the Manufacturer is responsible for the structural and pressure-retaining integrity of a vessel or part thereof, as established by conformance with the requirements of the rules of this Division and the requirements in the User’s Design Specification. The Manufacturer is also responsible for completing a Manufacturer’s Data Report for completed vessels or parts marked with the Certification Mark with the U2 Designator and class or the Certification Mark with the PRT Designator. A Manufacturer’s Design Report for Class 1 construction must be certified by a Certifying Engineer in accordance with Annex 2-B – Guide for Certifying a Manufacturer’s Design Report when any conditions specified in Paragraph 2.3.3.1 are performed, and a Manufacturer’s Design Report for all Class 2 construction must be certified by a Certifying Engineer. Qualifications and requirements for Certifying Engineers and Designers are provided in the Annex 2-J – Qualifications and Requirements for Certifying Engineers and Designers in the 2021 edition of Section VIII, Division 2 of the ASME BPVC. The 2007 edition of Section VIII, Division 2 of the ASME BPVC states that one or more Professional Engineers, registered in one or more of the states of the United States of America or the provinces of Canada and experienced in pressure vessel design, shall certify that the User’s Design Specification meets the requirements in paragraph 2.2.2, and shall apply the Professional Engineer seal in accordance with the required procedures. The Manufacturer must prepare, collect, and maintain construction records and documentation as fabrication progresses, to show compliance with the Manufacturer’s Design Report (e.g., NDE reports, repairs, deviations from drawings, etc.). An index of the construction records files, in accordance with the Manufacturer’s Quality Control system, shall be maintained current. These construction records shall be maintained by the Manufacturer for three years after stamping of the vessel.

Part 2 – Responsibilities and Duties, Paragraph 2.4 states that all references to Inspectors throughout Division 2 mean the Authorized Inspector. All inspections required by Division 2 must be by an Inspector regularly employed by an ASME accredited Authorized Inspection Agency, as defined in the latest edition of ASME QAI-1, *Qualifications for Authorized Inspection*, or by a company that manufacturers pressure vessels exclusively for its own use and not for resale that is defined as a User-Manufacturer. This is the only instance in which an Inspector may be in the employ of the Manufacturer. All Inspectors must have been qualified in accordance with ASME QAI-1. The 2007 edition of Section VIII, Division 2 of the ASME BPVC states that all Inspector's shall have been qualified by a written examination under the rules of any state of the United States, province of Canada, or other sovereign government, that has adopted the Code.

2.4 SECTION II – MATERIALS

Section II of the ASME BPVC is a Reference Code because it defines requirements for materials permitted for construction of boilers and pressure vessels that comply with rules specified in Construction Code such as Sections I and Sections VIII, Division 1, and Division 2. Section II of the 2007 and 2021 editions of the ASME BPVC is subdivided into Parts A through D as follows.

Part A — Ferrous Material Specifications

Part B — Nonferrous Material Specifications

Part C — Specifications for Welding Rods, Electrodes, and Filler Metals

Part D — Properties

Discussions about the scope, content, and history of Section II follow.

2.4.1 Material Specifications – Parts A, B, and C

The ASME Boiler and Pressure Vessel Committee and the American Society for Testing and Materials (ASTM) have cooperated for more than 50 years in the preparation of material specifications for ferrous and nonferrous materials adequate for ensuring the safety of pressure equipment. Specifications for ferrous and nonferrous materials permitted for design and fabrication of boilers and pressure vessels are provided in Section II, Parts A and B of the ASME BPVC.

In 1992, the ASME Board of Pressure Technology Codes and Standards endorsed the use of non-ASTM material for ASME BPVC applications. It is the intent to follow the procedures and practices currently in use to implement the adoption of non-ASTM materials. Methods for incorporating new material specifications into Section II of the ASME BPVC are discussed in Sect. 3.1 of this report.

In 1969, the American Welding Society (AWS) began publishing specifications for welding rods, electrodes, and filler metals that were issued by ASTM. The Boiler and Pressure Vessel Committee recognized this arrangement and is now working with AWS to publish specifications for welding rods, electrodes, and filler metals. Specifications for welding rods, electrodes, and filler metals permitted for boiler and pressure vessel construction are provided in Section II, Part C of the ASME BPVC.

Each material specification included in Section II, Parts A, B, and C of the ASME BPVC that is identical to its corresponding ASTM or AWS material specification is indicated by the ASME and the originating organization symbols. Material specifications prepared and copyrighted by ASTM, AWS, and other originating organizations are reproduced in Section II of the ASME BPVC with the permission of the respective Society. Additional discussion about materials permitted for design and fabrication of boilers and pressure vessels is presented in Sect. 3.1 of this report.

2.4.2 Material Properties – Part D

Section II, Part D of the ASME BPVC provides stress tables and tables of mechanical and physical properties corresponding to each of the material specifications included in Section II, Parts A and B of the

ASME BPVC. These values are used as input to design calculations performed in accordance with rules specified in other sections of the ASME BPVC. A historical perspective on the evolution of design stresses used in the ASME BPVC is provided in Appendix A of this report.

Stress tables in Section II, Part D in the 2021 edition of the ASME BPVC specify maximum allowable stress values, S, (Tables 1A, 1B, 3, 5A, and 5B) and design stress intensity values, S_m, (Tables 2A, 2B, and 4). Titles for these stress tables as noted in Table 2.2.

Table 2.2 Stress tables in Section II, Part D in the 2021 edition of the ASME BPVC

Table	Title
1A	Section I; Section III, Division 1, Classes 2 and 3; Section VIII, Division 1; and Section XII Maximum Allowable Stress Values, S, for Ferrous Materials
1B	Section I; Section III, Division 1, Classes 2 and 3; Section VIII, Division 1; and Section XII Maximum Allowable Stress Values, S, for Nonferrous Materials
2A	Section III, Division 1, Classes 1, MC and CS; Section III, Division 3; and Section III, Division 5 Design Stress Intensity Values, S_m, and Section VIII, Division 2, Class 1 Maximum Allowable Stress Values, S, for Ferrous Materials
2B	Section III, Division 1, Classes 1, MC and CS; Section III, Division 3; and Section III, Division 5 Design Stress Intensity Values, S_m, and Section VIII, Division 2, Class 1 Maximum Allowable Stress Values, S, for Nonferrous Materials
3	Section III, Division 1, Classes 2 and 3; Section VIII, Divisions 1 and 2; and Section XII Maximum Allowable Stress Values, S, for Bolting Materials
4	Section III, Division 1, Classes 1 and MC; Section III, Division 3; and Section III, Division 5 Design Stress Intensity Values, S_m, and Section VIII, Division 2 Maximum Allowable Stress Values, S, for Bolting Materials
5A	Section VIII, Division 2, Class 2 Maximum Allowable Stress Values, S, for Ferrous Materials
5B	Section VIII, Division 2, Class 2 Maximum Allowable Stress Values, S, for Nonferrous Materials

Mandatory Appendix 6 – Basis for Establishing Stress Values in Tables 6A, 6B, 6C, and 6D in Section II, Part D of the 2021 edition of the ASME BPVC provides the basis for establishing allowable stress values in Tables 6A, 6B, 6C, and 6D. Value in these tables govern allowable stresses for those materials used to construct heating boilers in accordance rules specified in Section IV of the ASME BPVC and are included for information only. Therefore, further discussions about Mandatory Appendix 6 are beyond the scope of this report.

Tables U and Y-1 provide tensile strength values and yield strength values, respectively, for ferrous and nonferrous materials. Physical properties (thermal conductivity, thermal diffusivity, thermal expansion, and density), Young's modulus, and Poisson's ratio values are tabulated in Section II, Part D, Tables TE, TCD, TM, and PRD of the ASME BPVC based on nominal material composition. Titles for these tables as noted in Table 2.3. Additional discussions about specific material properties are presented in Sects. 3.2 through 3.5 of this report.

Table 2.3 Table of mechanical and physical properties in Section II, Part D in the 2021 edition of the ASME BPVC

Table	Title
U	Tensile Strength Values, Su, for Ferrous and Nonferrous Materials

Y-1	Yield Strength Values, Sy, for Ferrous and Nonferrous Materials
Y-2	Factors for Limiting Permanent Strain in Austenitic Stainless Steels, High-Nickel Alloy Steels, Nickel, and Nickel Alloys
TE-1	Thermal Expansion for Ferrous Materials
TE-2	Thermal Expansion for Aluminum Alloys
TE-3	Thermal Expansion for Copper Alloys
TE-4	Thermal Expansion for Nickel Alloys
TE-5	Thermal Expansion for Titanium Alloys
TCD	Nominal Coefficients of Thermal Conductivity (TC) and Thermal Diffusivity (TD)
TM-1	Moduli of Elasticity *E* of Ferrous Materials for Given Temperatures
TM-2	Moduli of Elasticity *E* of Aluminum and Aluminum Alloys for Given Temperatures
TM-3	Moduli of Elasticity *E* of Copper and Copper Alloys for Given Temperatures
TM-4	Moduli of Elasticity *E* of High Nickel Alloys for Given Temperatures
TM-5	Moduli of Elasticity *E* of Titanium and Zirconium for Given Temperatures
PRD	Poisson's Ratio and Density of Materials

2.5 SECTION V – NONDESTRUCTIVE EXAMINATION

Section V of the ASME BPVC contains methods and requirements for nondestructive examination (NDE) used to detect surface and internal imperfections in boiler and pressure vessel materials, welds, fabricated parts, and components. The NDE methods covered in Section V include:

- radiographic examination
- ultrasonic examination
- liquid penetrant examination
- magnetic particle examination
- eddy current examination
- visual examination
- leak testing
- acoustic emission examination

Section V also provides requirements for:

- equipment
- procedure
- calibration
- examinations and inspections
- evaluation
- records and documentation

The 2021 edition of Section V of the ASME BPVC includes Subsection A – Nondestructive Methods of Examination, Subsection B – Documents Adopted by Section V, mandatory appendices, and nonmandatory appendices. Section V also covers requirements for the qualification of personnel, inspections, and examinations.

As a Reference Code, requirements in Section V are referenced in Construction Code such as Sections I and Sections VIII, Division 1 and Division 2 and other referencing documents.

2.6 SECTION IX – QUALIFICATION STANDARD FOR WELDING, BRAZING, AND FUSING PROCEDURES; WELDERS; BRAZERS; AND WELDING, BRAZING, AND FUSING OPERATORS

Qualification standards for welders, welding operators, brazers, brazing operators, and fusing operators including the procedures employed in welding, brazing, or plastic fusing are provided in Section IX of the ASME BPVC. As a Reference Code, requirements in Section IX are applicable to construction of components under the rules of the ASME BPVC; the ASME B31 Codes for Pressure Piping which includes rules for pressure retaining items such as heat exchanges; and other Codes, standards, and specifications that reference Section IX. As such, Section IX is an active document subject to constant review, interpretation, and improvement to recognize new developments on technology and research data. However, Section IX does not contain rules for production joining, nor does it contain rules to cover all factors affecting production material joining properties under all circumstances.

Where such factors are determined by the organization to affect material joining properties, the organization must address those factors in the Procedure Specification to ensure that the required properties are achieved in the production material joining process. Although the Procedure Specification is qualification in accordance with Section IX requirements, it does not guarantee that procedures and performance qualifications will be acceptable to a particular construction.

Requirements in the 2007 and 2021 editions of Section IX of the ASME BPVC for welding, brazing, and plastic fusing are subdivided into the following categories.

- General Requirements (2021 edition only)
- Procedure Qualifications
- Performance Qualifications
- Welding, Brazing, and Fusing Data

According to requirements specified in Paragraph QG-106 Organizational Responsibility in the 2021 edition of Section IX of the ASME BPVC, personnel performing supervisory activities specified in Section IX shall be designated by the organization with responsibility for certifying qualification documents. In addition, Procedure Specifications used by an organization having responsibility for operational control of material joining processes shall have been qualified by that organization.

The 2007 edition of Section IX of the ASME BPVC include Part QW Welding and Part QB Brazing but does not include Part QG General Requirements or Part QF Plastic Fusing as discussed in Table 9.9 of this report.

2.6.1 Procedure Specification and Procedure Qualifications Record (PQR)

Each material joining process that is used in the construction of components under the rules of the ASME BPVC and referenced in Section IX must be qualified. In general, a Welding Procedure Specification (WPS) is required for each joining process. A Procedure Specification lists the essential and nonessential variables as they apply to that process. When an essential variable must be changed beyond the range qualified and the change is not an editorial revision to correct an error, requalification of the Procedure Specification is required. If a change is made in a nonessential variable, the procedure need only be revised or amended to address the nonessential variable change. When toughness testing is required for

Welding Procedure Specification (WPS) qualification by the Construction Code, the supplementary essential variables become additional essential variables, and a change in these variables requires requalification of the Procedure Specification.

The purpose of the Procedure Specification and the Procedure Qualification Record (PQR) is to ensure the material joining process proposed for construction are capable of producing joints having the required mechanical properties for the intended application. Personnel performing the material joining procedure qualification test must be sufficiently skilled. The purpose of the procedure qualification test is to establish the mechanical properties of the joint produced by the material joining process and not the skill of the personnel using the material joining process. In addition, special consideration is given when toughness testing is required by other sections of the ASME BPVC. However, the toughness supplementary essential variables do not apply unless referenced by the Construction Code.

2.6.2 Performance Qualifications and Performance Qualifications Record

The purpose of performance qualification is to determine the ability of a person using a material joining process to produce a sound joint when using a procedure specification. As an example, performance qualification for welding is defined as the demonstration of a welder's or welding operator's ability to produce welds meeting prescribed standards. Generally, a welder or welding operator may be qualified by mechanical bending tests, or volumetric NDE of a test coupon, or the initial production weld. Brazers or brazing operators and fusing operators may not be qualified by volumetric NDE. The performance qualification record documents what occurred during the production of a test coupon by a person using one or more joining processes following an organization's procedure specification.

Articles in Section IX in the 2007 and 2021 editions of the ASME BPVC list separately the various processes with the factors (called variables) that effect the material joining operations. The performance qualifications are limited by essential variables that apply to the performance qualifications of each process.

2.6.3 Welding, Brazing, and Fusing Data

Welding and brazing data requirements provided in Section IX in the 2007 and 2021 editions and fusing data requirements provided in Section IX in the 2007 of the ASME BPVC include the variables grouped into categories such as joints, base materials and filler materials, positions, preheat and postweld heat treatment, gas, electrical characteristics, and technique. These variables tend to be process dependent and only apply as referenced for the applicable process.

2.7 RULES FOR IN-SERVICE INSPECTION

The ASME BPVC does not provide rules for in-service inspection of boilers and pressure vessels constructed in accordance with rules specified in Section I, Section VIII, Division 1, or Section VIII, Division 2 of the ASME BPVC. A discussion of in-service inspection and repair codes and standards applicable to boilers and pressure vessels constructed in accordance with rules specified in Section I, Section VIII, Division 1, or Section VIII, Division 2 of the ASME BPVC following construction (i.e., post-construction) is presented in Sect. 10 of this report.

In-service inspection requirements for nuclear power plant components are specified in Section XI – Rules for Inservice Inspection of Nuclear Power Plant Components of the 2007 and 2021 editions of the ASME BPVC. However, safety evaluations for in-service inspection requirements specified in Section XI are beyond the scope of this report.

2.8 SECTION XIII – RULES FOR OVERPRESSURE PROTECTION

The 2021 edition of the ASME BPVC includes a new Section XIII – Rules for Overpressure Protection. Like Sections II, V, and IX, Section XIII is a Reference Code as noted in Table 1.6. Requirements specified in Reference Codes are only mandatory when referenced from a Construction Code such as Sections I, VIII – Division 1, or VIII – Division 2.

Although all previous editions of the ASME BPVC prior to 2021 included requirements for overpressure protection, rules for protecting boiler and pressure vessel for overpressure conditions are being transferred to Section XIII. In addition, pressure relief device requirements have been transferred to Section XIII or restructured within new paragraphs. The new Section XIII is not intended to provide any new technical requirements from 2019. This first Section XIII edition is intended as an administrative action to incorporate all relief device requirements in a single section of the ASME BPVC. The Construction Codes provide a guide to the relocation of requirements as follows.

- Section I – Nonmandatory Appendix G
- Section VIII Division 1 – Nonmandatory Appendix PP
- Section VIII Division 2 – Annex 9-B (Informative)

Responsible for developing and administering this new section is assigned to the ASME Boiler and Pressure Vessel Committee on Overpressure Protection (XIII). Its charter is to establish:

1. rules relating to pressure integrity and performance governing the construction and installation of pressure relief devices. Construction, as used in this Charter, is limited to materials, design, fabrication, examination, inspection, testing and certification. Installation, as used in this Charter, is limited to the variables that affect the performance and safety function of pressure relief devices.
2. rules for device type certification of relieving capacity and flow resistance ratings including the rules for conducting the tests and analyses to determine the performance of pressure relief devices.
3. rules for overpressure protection by system design. These rules are intended for use in the Sections of the Boiler and Pressure Vessel Code and other Standards, for the purpose of providing overpressure protection, to the extent that they are specified in those Sections or Standards.

Requirements in Section XIII are also suitable for reference by other national and international organizations involved with the application of overpressure protection.

3. MATERIAL SPECIFICATIONS AND PROPERTIES

Section II of the ASME BPVC provides material specifications and material properties for materials permitted for construction of boilers and pressure vessels. It is subdivided into Parts A, B, C, and D as discussed in Sect. 2.4 of this report.

3.1 MATERIALS PERMITTED FOR DESIGN AND FABRICATION OF BOILERS AND PRESSURE VESSELS

Specifications for materials permitted for design and fabrication of boilers and pressure vessels are identified in Section II, Parts A, B, and C by the capital letter "S" followed by a series of symbols and alphanumeric characters. Examples of material specification identifiers follow.

Part A – Ferrous Material Specifications – SA-513, SA-1008/SA-1008M, SA/EN 10028-2

Part B – Nonferrous Material Specifications – SB-210, SB-249/SB-249M, SB/EN 1706, SF-468M

Part C – Specifications for Welding Rods, Electrodes, and Filler Metals – SFA-5.01M/SFA-5.01, SFA-5.13, SFA-5.36/SFA-5.36M

These identifiers remain in effect throughout the life of the specification even when the specification is revised, changed, or declared obsolete.

From time to time, it becomes necessary to remove specifications from Section II of the ASME BPVC. This occurs because the sponsoring society (e.g., ASTM, AWS, CEN, etc.) has notified ASME that the specification has either been replaced with another specification, or there is no known production or use of a material. Removal of a specification from Section II also results in concurrent removal of the same specification from Section IX and from ASME Boiler and Pressure Vessel Construction Codes that reference the material. This action effectively prohibits further use of the material for ASME boiler and pressure vessel construction.

Since the 1980s, when ASTM and ASME material specifications for steels are updated, they include limits on the amounts of residual elements that may be present in the steel. For example, ASTM and ASME material specifications published in the 1980s for carbon steel pipe did not provide limits on residual elements such as chromium, copper, nickel, molybdenum, and vanadium because they were not normally expected in carbon steels. However, these residual elements can affect weldability, fracture toughness, and strength. Material specifications for steels in the 2021 edition of Section II, Part A of the ASME BPVC now include limits on residual elements.

The Preface to the 2021 edition of Section II, Part A of the ASME BPVC provides additional information about the way existing material specifications are revised and new materials specifications are incorporated into Section II. It states:

The ASME Boiler and Pressure Vessel Committee has given careful consideration to each new and revised specification, and has made such changes as they deemed necessary to make the specification adaptable for Code usage. In addition, ASME has furnished ASTM with the basic requirements that should govern many proposed new specifications. Joint action will continue an effort to make the ASTM, AWS, and ASME specifications identical.

Section II, Part D, Mandatory Appendix 5 in the 2021 edition of the ASME BPVC provides further guidelines on the approval of new materials under the ASME Code. Code policy states:

It is expected that requests for Code approval will normally be for materials for which there is a recognized national or international specification. It is the policy of the ASME Boiler and

Pressure Vessel (BPV) Committee on Materials to approve, for inclusion in the Code Sections, only materials covered by specifications that have been issued by standards-developing organizations such as, but not limited to, American Petroleum Institute (API), American Society for Testing and Materials (ASTM), American Welding Society (AWS), Canadian Standards Association (CSA), European Committee for Standardization (CEN), Japan Industrial Standards (JIS), Standards Association of Australia (SAA), and China Standardization Committee (CSC).

Ferrous material specifications that were included in the 2007 edition of Section II, Part A of the ASME BPVC but are no longer permitted for design and fabrication of boilers and pressure vessels that comply with rules and requirements specified in the 2021 edition of the ASME BPVC are identified Table 3.1.

Table 3.1 Ferrous material specifications included in the 2007 edition but not included in the 2021 edition of Section II, Part A of the ASME BPVC

Specification	Title
SA-202/SA-202M	Pressure Vessel Plates, Alloy Steel, Chromium-Manganese-Silicon.
SA-275/SA-275M	Magnetic Particle Examination of Steel Forgings.
SA-494/SA-494M	Castings, Nickel and Nickel Alloy.

Some ferrous material specifications that were not included in the 2007 edition of Section II, Part A of the ASME BPVC but are now permitted for design and fabrication of boilers and pressure vessels that comply with rules and requirements specified in the 2021 edition of the ASME BPVC are identified Table 3.2. Other materials have been incorporated through Code Cases and are not included in this list.

Table 3.2 Ferrous material specifications not included in the 2007 edition but included in the 2021 edition of Section II, Part A of the ASME BPVC

Specification (See Note 1)	Title
SA-988/SA-988M	Specification for Hot Isostatically-Pressed Stainless Steel Flanges, Fittings, Valves, and Parts for High Temperature Service
SA-989/SA-989M	Specification for Hot Isostatically-Pressed Alloy Steel Flanges, Fittings, Valves, and Parts for High Temperature Service
SA/EN 10025-2	Specification for Hot Rolled Products of Structural Steels Part 2: Technical Delivery Conditions for Non-Alloy Structural Steels.
SA/EN 10028-4	Specification for Flat Products Made of Steels for Pressure Purposes Part 4: Nickel Alloy Steels with Specified Low Temperature Properties.
SA/EN 10028-7	Specification for Flat Products Made of Steels for Pressure Purposes Part 7: Stainless Steels.
SA/EN 10088-2	Specification for Stainless Steels Part 2: Technical Delivery Conditions for Sheet/Plate and Strip of Corrosion Resisting Steels for General Purposes.
SA/EN 10088-3	Specification for Stainless Steel Part 3: Technical Delivery Conditions for Semi-Finished Products, Bars, Rods, Wire, Sections, and Bright Products of Corrosion Resisting Steels for General Purposes.
SA/EN 10216-2	Specification for Seamless Steel Tubes for Pressure Purposes Part 2: Technical Delivery Conditions for Non-Alloy and Alloy Steel Tubes with Specified Elevated Temperature Properties.
SA/EN 10217-1	Specification for Welded Steel Tubes for Pressure Purposes Part 1: Technical Delivery Conditions for Non-Alloy Steel Tubes with Specified Room Temperature Properties.

SA/EN 10222-2	Specification for Steel Forgings for Pressure Purposes Part 2: Ferritic and Martensitic Steels with Specified Elevated Temperature Properties.
SA/GB 713	Specification for Steel Plates for Boilers and Pressure Vessels.
SA/IS 2062	Specification for Steel for General Structural Purposes.
SA/JIS G3118	Specification for Carbon Steel Plates for Pressure Vessels for Intermediate and Moderate Temperature Service.
SA/JIS G4303	Specification for Stainless Steel Bars.
SA/JIS G5504	Specification for Heavy-Walled Ferritic Spheroidal Graphite Iron Castings for Low Temperature Service.
SA/NF A 36-215	Specification for Weldable Fine Grain Steels for Transportation of Dangerous Substances.

Notes:

1. Material specifications listed in Table 3.2 of this report do not include those adopted for use through the Code Case approval process as discussed in Section 2 of this report.

Nonferrous material specifications that were not included in the 2007 edition of Section II, Part B of the ASME BPVC but are now permitted for design and fabrication of boilers and pressure vessels that comply with rules and requirements specified in the 2021 edition of the ASME BPVC are identified Table 3.3.

Table 3.3 Nonferrous material specifications not included in the 2007 edition but included in the 2021 edition of Section II, Part B of the ASME BPVC

Specification (See Note 1)	Title
SF-467	Specification for Nonferrous Nuts for General Use.
SF-467M	Specification for Nonferrous Nuts for General Use [Metric].
SF-468	Specification for Nonferrous Bolts, Hex Cap Screws, and Studs for General Use.
SF-468M	Specification for Nonferrous Bolts, Hex Cap Screws, and Studs for General Use [Metric].
SB-653/SB-653M	Specification for Seamless and Welded Zirconium and Zirconium Alloy Welding Fittings.
SB-666/SB-666M	Practice for Identification Marking of Aluminum and Magnesium Products.
SB-706	Specification for Seamless Copper Alloy (UNS No. C69100) Pipe and Tube.
SB-752/SB-752M	Specification for Castings, Zirconium-Base, Corrosion Resistant, for General Application
SB-834	Specification for Pressure Consolidated Powder Metallurgy Iron-Nickel-Chromium- Molybdenum (UNS N08367), Nickel-Chromium- Molybdenum-Columbium (Nb) (UNS N06625), Nickel- Chromium-Iron Alloys (UNS N06600 and N06690), and Nickel-Chromium-Iron- Columbium-Molybdenum (UNS N07718) Alloy Pipe Flanges, Fittings, Valves, and Parts
SB-956/SB-956M	Specification for Welded Copper and Copper-Alloy Condenser and Heat Exchanger Tubes with Integral Fins.

Notes:

1. Material specifications listed in Table 3.3 of this report do not include those adopted for use through the Code Case approval process as discussed in Section 2 of this report.

Specifications for welding rods, electrodes, and filler metals that were not included in the 2007 edition of Section II, Part C of the ASME BPVC but are now permitted for design and fabrication of boilers and pressure vessels that comply with rules and requirements specified in the 2021 edition of the ASME BPVC are identified Table 3.4.

Table 3.4 Specifications for welding rods, electrodes, and filler metals not included in the 2007 edition but included in the 2021 edition of Section II, Part C of the ASME BPVC

Specification	Title
SFA-5.02/SFA-5.02M	Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes
SFA-5.31	Specification for Fluxes for Brazing and Braze Welding
SFA-5.32/SFA-5.32M	Specification for Welding Shielding Gases
SFA-5.34/SFA-5.34M	Specification for Nickel-Alloy Electrodes for Flux Cored Arc Welding
SFA-5.36/SFA-5.36M	Specification for Carbon and Low alloy Steel Flux Cored Electrodes for Flux Cored Arc Welding and Metal Cored Electrodes for Gas Metal Arc Welding

The remainder of the material specifications included in Parts A, B, and C in the 2007 edition of Section II of the ASME BPVC are also included in Parts A, B, and C in the 2021 edition of Section II. However, changes or modifications to these specifications may have occurred between 2007 and 2021. A comparison of the text and figures in corresponding editions or revisions of these specifications to evaluate effects of changes on equivalent safety was not performed as part of this safety equivalency evaluation.

Prior to 1990, materials manufactured to older material specifications could be substituted for those materials under the latest edition of the ASME BPVC. This was a reasonable policy because material specifications typically change little and have years of proven satisfactory service history. As many material specifications changed in the 1980s and with the influx of imported materials, Code Case 2053 was issued in 1989 allowing use of materials made to older material specifications for new construction with certain restrictions. Text in Code Case 2053 (2001) states:

> *Inquiry: May material in inventory that meets the requirements of a Section II material specification that was superseded and meets the requirements of the current specification except for the more restrictive chemical compositional requirements of the current Section II specification, be used in Code construction?*
>
> *Reply: It is the opinion of the Committee that material in inventory that meets the requirements of a Section II material specification that was superseded, and meets the requirements of the current specification except for the more restrictive chemical composition requirements of the current Section II specification, may be used in Code construction provided the following requirements are met.*
>
> > *(a) There is no prohibition on the use of the specification that was superseded in the rules of the Code, providing that specification has been accepted by, and stress values published in the specific Code Section for which it is to be used.*
> >
> > *(b) The material shall have been melted when the chemical requirements of an ASME approved material specification that has been superseded were in effect.*

Code Case 2053 initially applied to Section I, Section IV, Section VIII, Division 1, and Section VIII, Division 2 of the ASME BPVC. However, Code Case 2053 was removed from Section I in 2001 and annulled in 2004 for all Sections of the ASME BPVC. Consequently, use of materials in inventory that do not meet the current material specification is not permitted.

Mandatory Appendix II in Section II, Parts A and B in the 2021 edition of the ASME BPVC provides the basis for use of acceptable ASME, ASTM, and non-ASTM editions. According to Mandatory Appendix II, which applies to Section II, Parts A and B, materials that comply with older material specifications may only be used if the earlier edition has been shown to meet the latest adopted edition.

3.2 TEMPERATURE-DEPENDENT AND TIME-DEPENDENT PROPERTIES

Criteria for establishing maximum allowable design stresses for Part A and Part B materials are specified in Section II, Part D – Properties of the ASME BPVC. A discussion of these criteria is presented in Sect. 2.4.2 of this report. Maximum allowable stresses based on these criteria are tabulated in Section II, Part D as discrete values for temperatures in the range of -20ºF to 100ºF and for each 50ºF increment between 150ºF and 1,650ºF.

3.3 TOUGHNESS PROPERTIES

The toughness of a material is a measure of its ability to resist tearing or cracking. Material toughness is commonly measured by the Charpy V-notch impact test method which is a standardized high strain-rate test used to determine the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of the material's notch toughness. Notch toughness values are needed to establish the temperature between ductile and brittle behavior as discussed in Sect. 4.1.3 of this report. Unlike certain ferrous materials, nonferrous alloys do not exhibit a ductile-brittle transition because they do not suffer a loss of impact resistance at low temperatures.

Some, but not all, material specifications included in Section II of the ASME BPVC require Charpy V-notch impact tests to verify that the material meets a minimum energy absorption value. As a supplement to prescribed minimum energy absorption values in these material specifications, rules specified in Section VIII, Divisions 1 and 2 of the ASME BPVC impose additional toughness requirements for avoiding brittle fracture.

As the role of fracture mechanics in avoiding brittle fracture has progressed over time, the importance of material toughness on boiler and pressure vessel safety is reflected in ASME BPVC changes to material toughness rules between the 2007 and 2021 editions. These rule changes depend on the application and the minimum design metal temperature and vary from one Section of the ASME BPVC to another. A comparison of toughness requirements specified in the 2007 and 2021 editions of the ASME BPVC is presented in Table 4.1 of this report.

3.4 FATIGUE PROPERTIES

Fatigue is progressive degradation of metal that occurs when a component is subjected to cyclic loading. Preventing fatigue failure requires reducing stresses and limiting the number of loading cycles. As discussed in Sect. 4.1.6 of this report, the ASME BPVC establishes fatigue margins based on two considerations: a factor of twenty on the number of cycles and a factor of two on stress. These limits are determined from fatigue test data obtained from a series of test specimens machined from the same material. Plots of fatigue test data used to construct design fatigue curves for carbon steels, low alloy steels, and 18-8 stainless steels are presented in ASME PTB-1-2014 [6]. Failure caused by cyclic loading and permitted stress ranges for cyclic loading are discussed in Sects. 4.1.6 and 4.7 of this report.

3.5 CORROSION PROPERTIES

Corrosion is the gradual destruction of a material by chemical or electrochemical reaction with the environment. Common types of corrosion that can occur when the material makes contacts with a corrosive environment include:

- atmospheric corrosion
- corrosion fatigue
- crevice corrosion
- environmentally assisted cracking
- galvanic corrosion
- hydrogen induced stress cracking
- intergranular corrosion
- pitting corrosion
- stress corrosion cracking
- sulfide stress cracking
- uniform corrosion

Additional information about degradation mechanisms that can adversely affect boiler and pressure vessel in-service performance is presented in standard API RP 571 [7].

The corrosion rate of metal in a particular environment can be determined by corrosion testing such as the simple weight loss test. However, other corrosion mechanisms such as stress corrosion cracking must be studied using more complex testing methods that involve exposure of a stressed material sample in the environment of interest.

Changes in the chemical composition of a material can significantly increase or decrease its rate of corrosion in a particular environment. For example, type 304 stainless steels are resistant to corrosion in demineralized water, whereas carbon steels corrode when exposed to demineralized water. Discussions about stress corrosion cracking and corrosion fatigue, which are failure modes that can adversely affect boiler and pressure vessel safety, are presented in Sect. 4.1.7 of this report.

4. DESIGN

The intent of design and fabrication rules in the ASME BPVC is to ensure that a boiler or pressure vessel will provide safe and satisfactory performance during its useful service life. However, compliance with these rules does not ensure a long service life nor does it guarantee a minimum design margin when the loadings and environmental conditions are more severe than those represented in the design basis. Responsibility for assuring safe and satisfactory in-service performance of a boiler or pressure vessel rests with both the user and the designer. These statements are supported by text in the Foreword for the 2021 edition of Section I of the ASME BPVC that states:

> *The objective of the rules is to afford reasonably certain protection of life and property, and to provide a margin or deterioration in service to give a reasonably long, safe period of usefulness.*
>
> *The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory.*

Boiler and pressure vessel users including pipeline and LNG facility operators are responsible for:

- providing the designer with a complete design basis for the boiler or pressure vessel:
- assuring that the materials used for construction are suitable for the intended service conditions: and
- installing, operating, and maintaining the boiler or pressure vessel within the design basis.

After a boiler or pressure vessel has been designed, constructed, and certificated in accordance with ASME BPVC rules, it is critically important from a safety viewpoint for users to ensure that each boiler or pressure vessel is protected by an overpressure protection system. Such overpressure protection systems must be capable of limiting pressure under both normal and abnormal operating scenarios to acceptable levels consistent with the design basis. Each user is also responsible for inspecting and maintaining the overpressure protection system throughout the service life of the boiler or pressure vessel. Rules for overpressure protection are provided in a completely new Section XIII – Rules for Overpressure Protection in the 2021 edition of the ASME BPVC as discussed in Sect. 2.8 of this report.

Although boiler and pressure vessel designers are responsible for complying with ASME BPVC rules and for demonstrating compliance with applicable equations when such equations are mandatory as stated above, they are also responsible for knowing when and how to apply these equations based an understanding of the engineering principles and design philosophy used to establish the primary, secondary, and peak stress limits. Limiting stresses that a boiler or pressure vessel may experience to those specified in the ASME BPVC is fundamental to satisfactory in-service performance within the design basis.

4.1 POTENTIAL FAILURE MODES

The four failure categories for boilers and pressure vessels are organized into the following groups.

1. Material
2. Design
3. Fabrication
4. Service

The various possible modes of failure which confront a boiler or pressure vessel designer are [6]:

- Excessive elastic deformation including elastic instability – Design and Fabrication
- Excessive plastic deformation (ductile rupture) – Design and Material
- Brittle fracture – Design, Material, and Fabrication
- Stress rupture / creep deformation (inelastic) – Design, Material, and Service
- Plastic instability – incremental collapse – Design and Service
- High strain – low-cycle fatigue – Design and Service
- Stress corrosion – Service
- Corrosion fatigue – Service

Safety criterion in the form of a design margin for each of these possible modes of failure can only be quantified on a case-by-case basis because design details, material properties, loading combinations, and environmental conditions have a significant effect on the true margin of safety for boilers and pressure vessels. Brief descriptions of the various failure mode that owners and designers must consider when specifying and designing boilers and pressure vessels follow.

4.1.1 Excessive Elastic Deformation and Elastic Instability

Excessive elastic deformation (deflection) and elastic instability (buckling) cannot be controlled by imposing upper limits on calculated stress alone because these behavioral phenomena are affected by component geometry, stiffness, and material properties. Excessive elastic deformation can occur when a component with inadequate stiffness experiences unwanted flexibility or unacceptable deflections. Buckling is characterized by a sudden sideways failure of a component subjected to high compressive stress, where the compressive stress at the point of failure is less than the compressive stress that the material is capable of withstanding. Forming and alignment tolerances can also contribute to excessive elastic deformation and elastic instability.

Special stress limits in the ASME BPVC are provided for elastic and inelastic instability, but the designer of a boiler or pressure vessel is responsible for applying engineering principles to understand and avoid in-service problems or failures caused by excessive elastic deformation and elastic instability.

4.1.1.1 Excessive Elastic Deformation and Elastic Instability Requirements in Section I

Appendix 3, Subpart 3 in the 2007 and 2021 editions of Section II, Part D of the ASME BPVC provides charts and tables for determining the shell thickness of components under external pressure that are designed and fabricated in accordance with rules specified in Section I of the ASME BPVC. According to Section II, Part D, Mandatory Appendix 3, Subpart 3, Paragraph 3-100 in the 2007 and 2021editions of the ASME BPVC:

> *The charts in Subpart 3 were established in order to facilitate a conservative approach in determining external pressure ratings for components covering a wide range of geometries, materials, and conditions. The methods provide for a uniform basis of calculation for the referencing Section; the use of the charts eliminates the need for complex calculations by equations and incorporates realistic factors of safety for components of widely varying length-to-diameter and diameter-to-thickness ratios.*

In addition, Section I, Paragraph PG-29.9 in the 2007 and 2021 editions of the ASME BPVC states:

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

To further address excessive elastic deformation and elastic instability for components under external pressure, Section I, Paragraph PG-28 in the 2021 edition of the ASME BPVC expands rules for:

1. thickness of cylindrical components under external pressure (Rules in Section I, Paragraph PFT-50 – Thickness of Furnaces and Tubes Under External Pressure in the 2007 edition were redesignated as Paragraph PG-28.1 in Section I of the 2021 edition of the ASME BPVC.)
2. welded access or inspection openings under external pressure (See Section I, Paragraph PG-28.2 in the 2021 edition of the ASME BPVC)
3. maximum allowable external working pressure for cylindrical components (Rules in Section I, Paragraph PFT-51 – Maximum Allowable Working Pressure in the 2007 edition were redesignated as Paragraph PG-28.3 in Section I of the 2021 edition of the ASME BPVC.)

4.1.1.2 Excessive Elastic Deformation and Elastic Instability Requirements in Section VIII, Division 1

Paragraph UG-28 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC specifies rules for the design of shells and tubes under external pressure given in this Division are limited to cylindrical shells, with or without stiffening rings, tubes, and spherical shells. Three typical forms of cylindrical shells are shown in Figure UG-28. Charts used in determining minimum required thicknesses of these components are given in Section II, Part D, Mandatory Appendix 3, Subpart 3, Paragraph 3-100 in the 2007 and 2021editions of the ASME BPVC as discussed in Sect. 4.1.1.1 of this report.

4.1.1.3 Excessive Elastic Deformation and Elastic Instability Requirements in Section VIII, Division 2

According to rules specified in Part 5, Paragraph 5.4.1.1 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC states:

> *In addition to evaluating protection against plastic collapse as defined in 5.2, a design factor for protection against collapse from buckling shall be satisfied to avoid buckling of components with a compressive stress field under applied design loads.*

Three alternative types of buckling analyses are included in Part 5, Paragraph 5.4 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC to evaluate structural stability from compressive stress fields. The design factor to be used in a structural stability assessment is based on the type of buckling analysis performed. These design factors are the same in the 2007 and 2021 editions. Minimum design factors are provided for use with shell components when the buckling loads are determined using a numerical solution (i.e., bifurcation buckling analysis or elastic-plastic collapse analysis). Bifurcation buckling is defined as the point of instability where there is a branch in the primary load versus displacement path for a structure. Unlike rules specified in Section VIII, Division 1, these buckling analyses do not reference the external pressure charts provided in Section II, Part D, Mandatory Appendix 3 in the 2007 and 2021editions of the ASME BPVC.

Related discussions about rules for protection against plastic collapse specified in Part 5, Paragraph 5.2 are presented in Sect. 4.8.2 of this report.

4.1.2 Excessive Plastic Deformation

The plastic deformation mode of failure (ductile rupture) is controlled by imposing limits on calculated stress. Primary stress limits and primary plus secondary stress limits in the ASME BPVC are intended to prevent excessive plastic deformation leading to incremental collapse and to provide a nominal margin on the ductile burst pressure. The designer of a boiler or pressure vessel is responsible for ensuring that the specified stress limits are not exceeded under all operating conditions defined by the user.

Rules for protection against plastic collapse are not specifically provided in Section I or Section VIII, Division 1 of the ASME BPVC. As discussed in Sect. 4.4.1 of this report, the maximum allowable stress for boilers and pressure vessels constructed in accordance with rules specified in Section I; Section VIII, Division 1; and Section VIII, Division 2 of the ASME BPVC is limited to two-thirds of the yield strength, $2/3\, S_y$, or less. This limit provides protection against plastic collapse and prevents excessive plastic deformation by ensuring elastic response for all operating conditions.

Rules for avoiding excessive plastic deformation are provided in Part 5, Paragraph 5.2 – Protection Against Plastic Collapse in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. Further technical discussions about plastic collapse are presented in Sect. 4.8 of this report.

4.1.3 Brittle Fracture

Brittle fracture is a failure mode that can occur without appreciable prior plastic deformation in metals that are under tensile stress. When local stresses in the area of a flaw reach the yield point, the metal may tear or form a crack, which can then grow suddenly through the thickness causing a catastrophic failure. The ability of a metal to resist tearing or cracking is a measure of its fracture toughness. Fracture toughness is a material property that often varies with temperature.

Brittle fracture is generally more of a concern for relatively thick metallic components compared to relatively thin metallic components. Thicker materials are more likely to have flaws, cracks, or other irregularities that act as stress raisers. Examples of stress raisers include welds with undercuts, grooves, or ridges. Ligaments between openings, changes in geometry at transitions between materials of different thickness, and nozzle-to-shell junctions can also act as stress raisers. These stress-raising irregularities, which are often referred to as notches, can cause stress concentrations equal to two or more times the nominal tensile stress.

Fracture mechanics is the field of engineering concerned with crack propagation in materials. It uses methods of analytical solid mechanics to calculate the driving force on a crack and those of experimental solid mechanics to characterize the material's fracture toughness. In fracture mechanics calculations, the value of the stress intensity factor, K_I, is a function on the applied stress and dimensions of the flaw. The calculated K_I must be less than the critical fracture toughness parameter, K_{Ic}, to avoid brittle fracture. In linear elastic fracture mechanics (LEFM) theory:

- fracture toughness, K_{Ic}, is a material property that varies with temperature.
- the allowable stress, σ, in the presence of a given flaw size, a, is proportional to the fracture toughness.
- the allowable flaw size for a given stress is proportional to the square of the fracture toughness as stated by the following equation.

$$\sigma^2 \pi a_c \propto K_{Ic}^2$$

- increasing K_{Ic} has a much larger influence on the allowable flaw size than on allowable stress, where a_c.is the critical flaw size.
- a stress equal to $0.8 S_y$ is approximately the upper bound stress limit for LEFM theory applicability.

Fracture mechanics equivalency studies show that the required stress intensity factor K_I, increases with an increase in the maximum allowable design stress from $S_T/4$ to $S_T/3.5$ and increases further when the maximum allowable design stress increases from $S_T/3$ to $S_T/2.4$ [8].

From an equivalency viewpoint, an increase in the maximum allowable design stress for a material with a critical flaw size, a_c, requires an increase in fracture toughness to maintain the same margin against brittle fracture. An increase in fracture toughness is also required with an increase in the maximum allowable design stress because surface and volumetric NDE techniques have flaw size detection limits. Increasing fracture toughness reduces the possibility that critical flaw sizes below the NDE detection limits result in brittle fracture.

Protection against brittle fracture is provided by material selection, rather than by analysis [6]. Measures for avoiding failure by brittle fracture involve:

- selecting materials with adequate fracture toughness for the service environment.
- conducting surface and volumetric NDE to detect defects that exceed acceptance criteria.
- reducing stress concentrations such as notches by eliminating stress raisers.
- using forming practices, welding procedures, welding materials, and postweld heat treatment processes that reduce the possibility of crack development.
- operating a boiler or pressure vessel at or above its minimum metal design temperature.
- providing a pressure relief system with a relieving capacity capable of preventing a pressure increase that causes stresses to exceed allowable stress limits.

Rules for avoiding brittle fracture focus on fracture toughness and vary from one Section and edition of the ASME BPVC to another. A comparison of toughness requirements specified in the 2007 and 2021 editions of the ASME BPVC is presented in Table 4.1.

Table 4.1 Comparison of toughness requirements specified in the 2007 and 2021 editions of the ASME BPVC

Safety-related Parameter	2007 Edition	2021 Edition
Material Toughness, Section I	Section I does not specify rules for material toughness. Section I, PG-99 Hydrostatic Test states: After a boiler has been completed (See PG-104), it shall be subjected to pressure tests using water at not less than ambient temperature, but in no case less than 70°F (20°C).	Section I does not specify rules for material toughness. Section I, PG-99 Hydrostatic Test states: After a boiler has been completed (See PG-104), it shall be subjected to pressure tests using water at not less than ambient temperature, but in no case less than 70°F (20°C).
Material Toughness, Section VIII, Division 1	Section VIII, Division 1, UG-84 Charpy Impact Tests Paragraph UG-84*(a) General* states: Charpy V-notch impact tests in accordance with the provisions of this paragraph shall be made on weldments and all materials for shells, heads, nozzles, and other vessel parts subject to stress due to pressure for which	Section VIII, Division 1, UG-84 Charpy Impact Tests Paragraph UG-84*(a) General* states: Charpy V-notch impact tests in accordance with the provisions of this paragraph shall be made on weldments and all materials for shells, heads, nozzles, and other vessel parts subject to stress due to pressure for which

Safety-related Parameter	2007 Edition	2021 Edition
	impact tests are required by the rules in Subsection C.	impact tests are required by the rules in Subsection C.
1. Toughness requirements for materials listed in Table UCS-23 Carbon and Low Alloy Steel and Table UHT-23 Ferritic Steels with Tensile Properties Enhanced by Heat Treatment	Section VIII, Division 1, UG-84 Charpy Impact Tests Paragraph UG-84*(c)(4)(-a)* states: The applicable minimum energy requirement for all specimen sizes for Table-UCS-23 materials having a specified minimum tensile strength less than 95,000 psi (655 MPa) shall be that shown in Figure UG-84.1. (Note: Figure UG-84.1 in the 2007 and 2021 editions are identical.) Paragraph UG-84*(c)(4)(-b)* states: The applicable minimum lateral expansion opposite the notch for all specimen sizes for Table UCS-23 materials, having a specified minimum tensile strength of 95,000 psi (655 MPa) or more, shall be as required in UHT-6*(a)(3)* and UHT-6*(a)(4)*. For UHT materials, all requirements of UHT-6*(a)(3)* and UHT-6*(a)(4)* shall apply. Section VIII, Division 1, UCS-66 Materials Paragraph UCS-66*(a)* states: Unless exempted by the rules of UG-20*(f)* or other rules of this Division, Fig. UCS-66 shall be used to establish impact testing exemptions for steels listed in Part UCS. When Fig. UCS-66 is used, impact testing is required for a combination of minimum design metal temperature (See UG-20) and thickness (as defined below) which is below the curve assigned to the subject material. If a minimum design metal temperature and thickness combination is on or above the curve, impact testing is not required by the rules of this Division, except as required by *(j)* below and UCS-67*(a)(2)* for weld metal.	Section VIII, Division 1, UG-84 Charpy Impact Tests Paragraph UG-84*(c)(4)(-a)* states: The applicable minimum energy requirement for all specimen sizes for Table-UCS-23 materials having a specified minimum tensile strength less than 95,000 psi (655 MPa) shall be that shown in Figure UG-84.1. (Note: Figure UG-84.1 in the 2007 and 2021 editions are identical.) Paragraph UG-84*(c)(4)(-b)* states: The applicable minimum lateral expansion opposite the notch for all specimen sizes for Table UCS-23 materials, having a specified minimum tensile strength of 95,000 psi (655 MPa) or more, shall be as required in UHT-6*(a)(3)* and UHT-6*(a)(4)*. For UHT materials, all requirements of UHT-6*(a)(3)* and UHT-6*(a)(4)* shall apply. Section VIII, Division 1, UCS-66 Materials Paragraph UCS-66*(a)* states: Unless exempted by the rules of UG-20*(f)* or other rules of this Division, Figure UCS-66 shall be used to establish impact testing exemptions for steels listed in Part UCS. When Figure UCS-66 is used, impact testing is required for a combination of minimum design metal temperature (See UG-20) and governing thickness (as defined below) that is below the curve assigned to the subject material. If a minimum design metal temperature and governing thickness combination is on or above the curve, impact testing is not required by the rules of this Division, except as required by *(j)* below and UCS-67*(a)(3)* for weld metal. Toughness requirements specified in Paragraph UG-84 for materials listed in Table UCS 23 Carbon and Low Alloy Steel and Table UHT 23 Ferritic Steels with Tensile Properties Enhanced by Heat Treatment are the same in the 2007 and

Safety-related Parameter	2007 Edition	2021 Edition
		2021 editions of Section VIII, Division 1 of the ASME BPVC.
2. Toughness requirements for materials listed in Table UHA-23 High Alloy Steel	Section VIII, Division 1, UG-84 Charpy Impact Tests Paragraphs UG-84(*c*)(*4*)(*b*) state that for Table UHA-23 materials, all requirements of UHA-51 shall apply. Paragraph UHA-51 in 2021 editions of Section VIII, Division 1 of the ASME BPVC states: Impact tests, as prescribed in UHA-51*(a)*, shall be performed on materials listed in Table UHA-23 for all combinations of materials and minimum design metal temperatures (MDMTs) except as exempted in UHA-51*(d), (e), (f), (g), (h),* or *(i)*. Impact tests are not required where the maximum obtainable Charpy specimen has a width along the notch less than 0.099 in. (2.5 mm).	Section VIII, Division 1, UG-84 Charpy Impact Tests Paragraphs UG-84(*c*)(*4*)(-*b*) state that for Table UHA-23 materials, all requirements of UHA-51 shall apply. Paragraph UHA-51 in 2021 editions of Section VIII, Division 1 of the ASME BPVC states: Impact tests, as prescribed in *(a)*, shall be performed on materials listed in Table UHA-23 for all combinations of materials and MDMTs except as exempted in *(d), (e), (f), (g), (h),* or *(i)*. Impact testing is required for UNS S17400 materials. Impact tests are not required where the maximum obtainable Charpy specimen has a width along the notch less than 0.099 in. (2.5 mm). As an alternative method to impact tests, ASTM E1820 J_{Ic} tests are allowed when the MDMT is colder than -320°F (-196°C). See Figures JJ-1.2-1 through JJ-1.2-5 for flowchart illustrations of impact testing requirements. (Note: The impact testing requirement for UNS S17400 materials and the alternative method to impact tests, which are allowed in the 2021 editions of Section VIII, Division 1 of the ASME BPVC, were added to Paragraph UHA-51 in the 2007 editions of Section VIII, Division 1 of the ASME BPVC.) Toughness requirements specified in Paragraph UG-84 for materials listed in listed in Table UHA-23 – High Alloy Steel are the same in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC.
3. Toughness Requirements for Nonferrous Metals	Section VIII, Division 1, Paragraph UNF-65 Low Temperature Operation states: The materials listed in Tables UNF-23.1 through UNF-23.5, together with deposited weld metal within the range of composition for material in that Table, do not undergo a marked drop in impact resistance at subzero temperature. Therefore, no additional	Section VIII, Division 1, Paragraph UNF-65 – Low Temperature Operation states: The materials listed in Tables UNF-23.1 through UNF-23.5, together with deposited weld metal within the range of composition for material in that Table, do not undergo a marked drop in impact resistance at subzero temperature. Therefore, no additional

Safety-related Parameter	2007 Edition	2021 Edition
	requirements are provided for wrought aluminum alloys when they are used at temperatures down to -452°F (-269°C); for copper and copper alloys, nickel and nickel alloys, and cast aluminum alloys when they are used at temperatures down to -325°F (-198°C); and for titanium or zirconium and their alloys used at temperatures down to -75°F (-59°C).	requirements are provided for wrought aluminum alloys when they are used at temperatures down to -452°F (-269°C); for copper and copper alloys, nickel and nickel alloys, and cast aluminum alloys when they are used at temperatures down to -325°F (-198°C); and for titanium or zirconium and their alloys used at temperatures down to -75°F (-59°C). Toughness requirements specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC for nonferrous materials are the same.
4. Toughness Requirements for Cr-Mo Steels	Section VIII, Division 1, Mandatory Appendix 31 Rules for Cr–Mo Steels with Additional Requirements for Welding and Heat Treatment Paragraph 31-5 Toughness Requirements states: The minimum toughness requirements for base metal, weld metal, and heat affected zone, after exposure to the simulated postweld heat treatment Condition B, shall be as follows: The average impact energy of three specimens shall be 40 ft-lb with only one in the set equal to 35 ft-lb min.	Section VIII, Division 1, Mandatory Appendix 31 Rules for Cr–Mo Steels with Additional Requirements for Welding and Heat Treatment Paragraph 31-5 Toughness Requirements states: The minimum toughness requirements for base metal, weld metal, and heat-affected zone, after exposure to the simulated postweld heat treatment Condition B, shall be as follows: The average impact energy of three specimens shall be 40 ft-lb with only one in the set equal to 35 ft-lb min. Toughness requirements specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC for Cr-Mo Steels are the same.
Material Toughness, Section VIII, Division 2	Section VIII, Division 2, Part 3 – Material Requirements, Paragraph 3.11 Material Toughness Requirements Paragraph 3.11.1.1 states: Charpy V-notch impact tests shall be made for materials used for shells, heads, nozzles, and other pressure containing parts, as well as for the structural members essential to structural integrity of the vessel, unless exempted by the rules of paragraph 3.11.	Section VIII, Division 2, Part 3 – Material Requirements, Paragraph 3.11 Material Toughness Requirements Paragraph 3.11.1.1 states: Charpy V-notch impact tests shall be made for materials used for shells, heads, nozzles, and other pressure containing parts, as well as for the structural members essential to structural integrity of the vessel, unless exempted by the rules of paragraph 3.11.
1. Toughness requirements for Carbon Steel and Low Alloy	Section VIII, Division 2, Part 3 – Material Requirements, Paragraph 3.11 Material Toughness Requirements	Section VIII, Division 2, Part 3 – Material Requirements, Paragraph 3.11 Material Toughness Requirements

Safety-related Parameter	2007 Edition	2021 Edition
Materials listed in Table 3-A.1	Paragraph 3.11.1.1(a) states: Toughness requirements for materials listed in Table 3-A.1 (carbon and low alloy steel materials except bolting materials) are given in 3.11.2. Paragraph 3.11.2.1(b) states: When impact testing is necessary, the following toughness values are required. (1) If the specified minimum tensile strength is less than 655 MPA (95 ksi), then the required minimum energy requirement for all specimen sizes shall be that shown in Figure 3.3 and Figure 3.4 for vessel parts not subject to postweld heat treatment (PWHT) and vessel parts subject to PWHT, respectively, multiplied by the ratio of the actual specimen width along the notch to the width of a full-size specimen, except as otherwise provided in paragraph 3.11.7.2.b. (2) If the specified minimum tensile strength is greater than or equal to 655 MPa (95 ksi), then the minimum lateral expansion (See Figure 3.5) opposite the notch for all specimen sizes shall not be less than the values shown in Figure 3.6. Minimum impact energy limits for carbon and low alloy steels with tensile strength less than 95 ksi range from 20 to 61 ft-lb depending on the minimum specified yield strength and thickness (See Part 3, Figures 3.3 and 3.4). Minimum lateral expansion limits for carbon and low alloy steels with tensile strength equal to or greater than 95 ksi range from 0.015 to 0.025 in. depending on the thickness (See Part 3, Figure 3.6).	Paragraph 3.11.1.1*(a)* states: Toughness requirements for materials listed in Table 3-A.1 (carbon and low alloy steel materials except bolting materials) are given in 3.11.2. Paragraph 3.11.2.1*(b)* states: When impact testing is necessary, the following toughness values are required. *(1)* If the specified minimum tensile strength is less than 655 MPa (95 ksi), then the required minimum energy for all specimen sizes shall be that shown in Figure 3.3 and Figure 3.4 for vessel parts not subject to postweld heat treatment (PWHT) and vessel parts subject to PWHT or nonwelded parts, respectively, multiplied by the ratio of the actual specimen width along the notch to the width of a full-size specimen, except as otherwise provided in 3.11.7.2*(b)*. *(2)* If the specified minimum tensile strength is greater than or equal to 655 MPa (95 ksi), then the minimum lateral expansion (See Figure 3.5) opposite the notch for all specimen sizes shall not be less than the values shown in Figure 3.6. Minimum impact energy limits for carbon and low alloy steels with tensile strength less than 95 ksi range from 20 to 61 ft-lb depending on the minimum specified yield strength and thickness (See Part 3, Figures 3.3 and 3.4). Minimum lateral expansion limits for carbon and low alloy steels with tensile strength equal to or greater than 95 ksi range from 0.020 to 0.032 in. depending on the thickness (See Part 3, Figure 3.6). As discussed in Sect. 4.1.3.3 of this report, the minimum lateral expansion values permitted in the 2021 edition for materials listed in Table 3-A.1 are larger than the minimum lateral expansion values permitted in the 2007 edition of Section VIII, Division 2 of the ASME BPVC. Consequently, toughness requirements in the 2021 edition of Section VIII, Division 2

Safety-related Parameter	2007 Edition	2021 Edition
		of the ASME BPVC for materials listed in Table 3-A.1 are more stringent than those in the 2007 edition for materials listed in Table 3-A.1.
2. Toughness requirements for Quenched and Tempered Steels with Enhanced Tensile Properties Listed in Table 3 A.2	Section VIII, Division 2, Part 3 – Material Requirements, Paragraph 3.11 Material Toughness Requirements Paragraph 3.11.1.1(b) states: Toughness requirements for materials listed in Table 3-A.2 (quenched and tempered steels with enhanced tensile properties) are given in 3.11.3. Paragraph 3.11.3.1 Toughness Requirements for Quenched and Tempered Ferritic Steels states: (a) All quenched and tempered steels listed in Table 3-A.2 shall be subject to Charpy V-notch testing. (b) Impact tests shall be conducted at a temperature not warmer than the MDMT determined in 4.1.5.2(d). However, in no case shall the impact test temperature be warmer than 0°C (32°F). (c) Materials may be used at temperatures colder than the MDMT as permitted below. 3.11.3.2 Impact Testing. (d) The minimum lateral expansion shall be in accordance with 3.11.2.1(b)(2). Paragraph 3.11.2.1(b) states: When impact testing is necessary, the following toughness values are required. (1) If the specified minimum tensile strength is less than 655 MPa (95 ksi), then the required minimum energy for all specimen sizes shall be that shown in Figure 3.3 and Figure 3.4 for vessel parts not subject to postweld heat treatment (PWHT) and vessel parts subject to PWHT or nonwelded parts, respectively, multiplied by the ratio of the actual specimen width along the notch to the width of a full-size specimen, except as otherwise provided in 3.11.7.2(b). (2) If the specified minimum tensile strength is greater than or equal to 655 MPa (95 ksi), then the minimum lateral	Section VIII, Division 2, Part 3 – Material Requirements, Paragraph 3.11 Material Toughness Requirements Paragraph 3.11.1.1*(b)* states: Toughness requirements for materials listed in Table 3-A.2 (quenched and tempered steels with enhanced tensile properties) are given in 3.11.3. Paragraph 3.11.3.1 Toughness Requirements for Quenched and Tempered Ferritic Steels states: *(a)* All quenched and tempered steels listed in Table 3-A.2 shall be subject to Charpy V-notch testing. *(b)* Impact tests shall be conducted at a temperature not warmer than the MDMT determined in 4.1.5.2*(d)*. However, in no case shall the impact test temperature be warmer than 0°C (32°F). *(c)* Materials may be used at temperatures colder than the MDMT as permitted below. 3.11.3.2 Impact Testing. *(d)* The minimum lateral expansion shall be in accordance with 3.11.2.1*(b)(2)*. Paragraph 3.11.2.1*(b)* states: When impact testing is necessary, the following toughness values are required. *(1)* If the specified minimum tensile strength is less than 655 MPa (95 ksi), then the required minimum energy for all specimen sizes shall be that shown in Figure 3.3 and Figure 3.4 for vessel parts not subject to postweld heat treatment (PWHT) and vessel parts subject to PWHT or nonwelded parts, respectively, multiplied by the ratio of the actual specimen width along the notch to the width of a full-size specimen, except as otherwise provided in 3.11.7.2*(b)*. *(2)* If the specified minimum tensile strength is greater than or equal to 655 MPa (95 ksi), then the minimum lateral

Safety-related Parameter	2007 Edition	2021 Edition
	expansion (See Figure 3.5) opposite the notch for all specimen sizes shall not be less than the values shown in Figure 3.6. Minimum impact energy limits for carbon and low alloy steels with tensile strength less than 95 ksi range from 20 to 61 ft-lb depending on the minimum specified yield strength and thickness (See Part 3, Figures 3.3 and 3.4). Minimum lateral expansion limits for carbon and low alloy steels with tensile strength equal to or greater than 95 ksi range from 0.015 to 0.025 in. depending on the thickness (See Part 3, Figure 3.6). 3.11.3.3 Drop-Weight Tests. (a) When the MDMT is colder than -29°C (-20°F), drop-weight tests as defined by ASTM E208, Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels, shall be made on all materials listed in Table 3A.2, with the following exceptions: (d) Required Test Results – Each of the two test specimens shall meet the "no-break" criterion, as defined by ASTM E208, at the test temperature.	expansion (See Figure 3.5) opposite the notch for all specimen sizes shall not be less than the values shown in Figure 3.6. Minimum impact energy limits for carbon and low alloy steels with tensile strength less than 95 ksi range from 20 to 61 ft-lb depending on the minimum specified yield strength and thickness (See Part 3, Figures 3.3 and 3.4). Minimum lateral expansion limits for carbon and low alloy steels with tensile strength equal to or greater than 95 ksi range from 0.020 to 0.032 in. depending on the thickness (See Part 3, Figure 3.6). 3.11.3.3 Drop-Weight Tests. *(a)* When the MDMT is colder than -29°C (-20°F), drop-weight tests as defined by ASTM E208, Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels, shall be made on all materials listed in Table 3A.2, with the following exceptions: *(d)* Required Test Results – Each of the two test specimens shall meet the "no-break" criterion, as defined by ASTM E208, at the test temperature. Note: Refer to the discussions in Sect. 4.1.3.3 of this report concerning differences in Figure 3.6 between the 2007 and 2021 editions of the of Section VIII, Division 2 of the ASME BPVC.
3. Toughness requirements for High Alloy Steel listed in Table 3-A.3	Section VIII, Division 2, Part 3 – Material Requirements, Paragraph 3.11 Material Toughness Requirements Paragraph 3.11.1.1*(c)* states: Toughness requirements for materials listed in Table 3-A.3 (high alloy steels except bolting materials) are given in 3.11.4. Paragraph 3.11.4 High Alloy Steels Except Bolting 3.11.4.1 Toughness Requirements for High Alloy Steels. states:	Section VIII, Division 2, Part 3 – Material Requirements, Paragraph 3.11 Material Toughness Requirements Paragraph 3.11.1.1*(c)* states: Toughness requirements for materials listed in Table 3-A.3 (high alloy steels except bolting materials) are given in 3.11.4. Paragraph 3.11.4 High Alloy Steels Except Bolting 3.11.4.1 Toughness Requirements for High Alloy Steels. states:

Safety-related Parameter	2007 Edition	2021 Edition
	(a) Impact tests shall be performed on high alloy materials listed in Table 3.A.3 for all combinations of materials and MDMTs except as exempted by paragraph 3.11.4.3 or 3.11.4.5. (b) When impact testing is required, the minimum lateral expansion opposite the notch shall be 0.38 mm (0.015 in.) for MDMTs of -196°C (-320°F) and warmer. For MDMTs colder than this temperature, production welding processes shall be limited to shielded metal arc welding (SMAW), gas metal arc welding (GMAW), submerged arc welding (SAW), plasma arc welding (PAW), and gas tungsten arc welding (GTAW).	*(a)* Impact tests shall be performed on high alloy materials listed in Table 3-A.3 for all combinations of materials and MDMTs except as exempted by 3.11.4.3 or 3.11.4.5. *(b)* When the MDMT is -196°C (-320°F) and warmer, impact tests shall be conducted at the MDMT or colder, and the minimum lateral expansion opposite the notch shall be no less than 0.38 mm (0.015 in.) for MDMTs of -196°C (-320°F) and warmer. *(c)* When the MDMT is colder than -196°C (-320°F), production welding processes shall be limited to shielded metal arc welding (SMAW), gas metal arc welding (GMAW), submerged arc welding (SAW), plasma arc welding (PAW), and gas tungsten arc welding (GTAW). Requirements specified in Part 3, Paragraph 3.11.4.1*(b)* and *(c)* are the same in the 2007 and 2021 edition of Section VIII, Division 2 of the ASME BPVC.
4. Toughness requirements for nonferrous alloys listed in Tables 3-A.4 through 3-A.7	Section VIII, Division 2, Part 3 – Material Requirements, Paragraph 3.11 Material Toughness Requirements Paragraph 3.11.1.1(d) states: Toughness requirements for materials listed in Table 3-A.4 (non-ferrous alloy) are given in 3.11.5. Paragraph 3.11.5 Nonferrous Alloys 3.11.5.1 state: Non-Ferrous materials listed in Tables 3.A.4 thru 3.A.7, together with deposited weld metal within the range of composition for material in that Table, do not undergo a marked drop in impact resistance at subzero temperature. Therefore, additional requirements are not specified for: (a) Wrought aluminum alloys when they are used at temperature down to -269°C (-452°F); (b) Copper and copper alloys, nickel and nickel alloys, and cast aluminum alloys when they are used at temperatures down to -198°C -325°F); and (c) Titanium or zirconium and their alloys used at temperatures down to -59°C (-75°F).	Section VIII, Division 2, Part 3 – Material Requirements, Paragraph 3.11 Material Toughness Requirements Paragraph 3.11.1.1*(d)* states: Toughness requirements for materials listed in Tables 3-A.4 through 3-A.7 (nonferrous alloy) are given in 3.11.5. Paragraph 3.11.5 Nonferrous Alloys 3.11.5.1 state: Nonferrous materials listed in Tables 3-A.4 through 3-A.7, together with deposited weld metal within the range of composition for material in that Table, do not undergo a marked drop in impact resistance at subzero temperature. Therefore, additional requirements are not specified for: *(a)* Wrought aluminum alloys when they are used at temperature down to -269°C (-452°F); *(b)* Copper and copper alloys, nickel and nickel alloys, and cast aluminum alloys when they are used at temperatures down to -198°C (-325°F); and *(c)* Titanium or zirconium and their alloys used at temperatures down to -59°C (-75°F).

Safety-related Parameter	2007 Edition	2021 Edition
		Toughness requirements specified in Part 3, Paragraph 3.11.5.1 are the same in the 2007 and 2021 edition of Section VIII, Division 2 of the ASME BPVC.
5. Toughness requirements for Bolting Materials	Section VIII, Division 2, Part 3 – Material Requirements, Paragraph 3.11 Material Toughness Requirements Paragraph 3.11.1.1*(e)* states: Toughness requirements for bolting materials are given in 3.11.6. Paragraph 3.11.6 Bolting Materials 3.11.6.1 Bolting Materials for Use with Flanges Designed to Paragraph 4.16 state: *(a)* Impact tests are not required for bolting materials listed in Tables 3.4, 3.5, 3.6, and 3.7 when used at MDMTs equal to or warmer than those shown in these Tables. *(b)* Bolting materials to be used for colder temperatures than those shown in Tables 3.4 - 3.7 shall conform to SA-320, except that the toughness criterion shall be Charpy V-notch with acceptance criteria in accordance with 3.11.2 or 3.11.4, as applicable. 3.11.6.2 Bolting Materials for Use with Flanges Designed to Part 5 of This Division states: Impact testing is required for the ferrous bolting materials listed in Table 3.A.11 for use with flanges designed in accordance with Part 5 of this Division. The average for three Charpy V-notch impact specimens shall be at least 41 J (30 ft-lb), with the minimum value for any individual specimen not less than 34 J (25 ft-lb).	Section VIII, Division 2, Part 3 – Material Requirements, Paragraph 3.11 Material Toughness Requirements Paragraph 3.11.1.1*(e)* states: Toughness requirements for bolting materials are given in 3.11.6. Paragraph 3.11.6 Bolting Materials 3.11.6.1 Bolting Materials for Use with Flanges Designed to 4.16 state: *(a)* Impact tests are not required for bolting materials listed in Tables 3.4, 3.5, 3.6, and 3.7 when used at MDMTs equal to or warmer than those shown in these Tables. *(b)* Bolting materials to be used for colder temperatures than those shown in Tables 3.4 through 3.7 shall conform to SA-320, except that the toughness criterion shall be Charpy V-notch with acceptance criteria in accordance with 3.11.2 or 3.11.4, as applicable. 3.11.6.2 Bolting Materials for Use with Flanges Designed to Part 5 of This Division states: Impact testing is required for the ferrous bolting materials listed in Table 3-A.11 for use with flanges designed in accordance with Part 5 of this Division. The average for three Charpy V-notch impact specimens shall be at least 41 J (30 ft-lb), with the minimum value for any individual specimen not less than 34 J (25 ft-lb). Toughness requirements specified in Part 3, Paragraph 3.11.6 are the same in the 2007 and 2021 edition of Section VIII, Division 2 of the ASME BPVC.
6. Toughness requirements for Cr-Mo Steels	Section VIII, Division 2, Part 3, Paragraph 3.4 Supplemental Requirements for Cr–Mo Steels Paragraph 3.4.1 General	Section VIII, Division 2, Part 3, Paragraph 3.4 Supplemental Requirements for Cr–Mo Steels Paragraph 3.4.1 General

Safety-related Parameter	2007 Edition	2021 Edition
	3.4.1.1 The rules in paragraph 3.4 include supplemental requirements for fabrication and testing for Cr-Mo steels. The materials and appropriate specifications covered by this paragraph are listed in Table 3.1. 3.4.5 Toughness Requirements The minimum toughness requirements for base metal, weld metal, and heat affected zone, after exposure to the simulated postweld heat treatment Condition B, are shown in Table 3.3. If the material specification or other parts of this Division have more demanding toughness requirements, they shall be met. Table 3.3 Toughness Requirements for 2.25Cr–1Mo Materials states: • Average impact energy of 3 specimens is 54J (40 ft-lb) tested at the MDMT. • Only one in the set 48 J (35 ft-lb).	3.4.1.1 The rules in 3.4 include supplemental requirements for fabrication and testing for Cr-Mo steels. The materials and appropriate specifications covered by this paragraph are listed in Table 3.1. 3.4.5 Toughness Requirements The minimum toughness requirements for base metal, weld metal, and heat-affected zone, after exposure to the simulated postweld heat treatment Condition B, are shown in Table 3.3. If the material specification or other parts of this Division have more demanding toughness requirements, they shall be met. Table 3.3 Toughness Requirements for 2.25Cr–1Mo Materials states: • Average impact energy of 3 specimens is 54J (40 ft-lb) tested at the MDMT. • Only one in the set 48 J (35 ft-lb). Toughness requirements specified in Table 3.3 are the same in the 2007 and 2021 edition of Section VIII, Division 2 of the ASME BPVC.

Discussions of changes in fracture toughness rules between the 2007 and the 2021 editions of the ASME BPVC follow.

4.1.3.1 Toughness Requirements in Section I

Boilers that are designed and fabricated in accordance with rules specified in Section I of the ASME BPVC operate at elevated temperatures where brittle fracture is a very unlikely mode of failure. Therefore, no fracture toughness requirements are provided in either the 2007 or the 2021 edition of Section I of the ASME BPVC. However, as a precaution against brittle fracture, hydrostatic pressure testing rules specified in Paragraph PG-99 in the 2007 and 2021 editions of Section I of the ASME BPVC state that after a boiler has been completed, it must be subjected to pressure tests using water at not less than ambient temperature, but in no case less than 70°F (20°C).

4.1.3.2 Toughness Requirements in Section VIII, Division 1

Toughness Requirements for Carbon and Low Alloy Steels and Ferritic Steels with Tensile Properties Enhanced by Heat Treatment

Toughness requirements for materials listed in Table UCS-23 Carbon and Low Alloy Steel and Table UHT-23 – Ferritic Steels with Tensile Properties Enhanced by Heat Treatment are specified in Paragraph UG-84 – Charpy Impact Tests in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC.

Paragraph UG-84*(c)(4)(-a)* in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC states:

> *Except for materials produced and impact tested in accordance with the requirements in the specifications listed in General Note (c) of Figure UG-84.1, the applicable minimum energy requirement for all specimen sizes for Table UCS-23 materials having a specified minimum tensile strength less than 95,000 psi (655 MPa) shall be that shown in Figure UG-84.1, multiplied by the ratio of the actual specimen width along the notch to the width of a full-size (10 mm × 10 mm) specimen, except as otherwise provided in (2)(-a) above.*

Figure UG-84.1, which is the same in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC, is a plot of impact energy versus maximum nominal thickness for materials or welds having a specified minimum tensile strength of less than 95,000 psi (655 MPa). Corresponding plots based on metric units presented in Figure UG-84.1M in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC are also the same.

Paragraphs UG-84*(c)(4)(-b)* in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC state that the applicable minimum lateral expansion opposite the notch for all specimen sizes for Table UCS-23 materials, having a specified minimum tensile strength of 95,000 psi (655 MPa) or more, shall be as required in UHT-6*(a)(3)* and UHT-6*(a)(4)*. For Table UHT-23 materials, all requirements of Paragraphs UHT-6*(a)(3*) and UHT-6*(a)(4*) shall apply. Requirements specified in UHT-6*(a)(3)* and UHT-6*(a)(4)* follow.

> *UHT-6(a)(3) Each of the three specimens tested shall have a lateral expansion opposite the notch not less than the requirements shown in Figure UHT-6.1.*
>
> *UHT-6(a)(4) If the value of lateral expansion for one specimen is less than that required in Figure UHT-6.1 but not less than 2/3 of the required value, a retest of three additional specimens may be made, each of which must be equal to or greater than the required value in Figure UHT-6.1. Such a retest shall be permitted only when the average value of the three specimens is equal to or greater than the required value in Figure UHT-6.1. If the values required are not obtained in the retest or if the values in the initial test are less than the values required for retest, the material may be reheat treated. After reheat treatment, a set of three specimens shall be made, each of which must be equal to or greater than the required value in Figure UHT-6.1.*

Figures UHT-6.1 and UHT-6.1M, which are the same in both the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC, are plots of Charpy V-notch impact test requirements based on customary and metric units, respectively. These figures present the required lateral expansion as a function of material thickness. According to Figure UHT-6.1, minimum lateral expansion values for material thicknesses up to 1.25 in. equal 15 mils and for material thicknesses ranging from 3 to 4 in. equal 25 mils. Minimum lateral expansion values for material thicknesses ranging from 1.25 to 3 in. vary linearly from 15 to 25 mils.

Exemptions from mandatory impact testing are specified in Paragraph UG-20*(f)* in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC as follows.

> *(f) Impact testing per UG-84 is not mandatory for pressure vessel materials that satisfy all of the following:*
>
> > *(1) The material shall be limited to P-No. 1, Gr. No. 1 or 2, and the thickness, as defined in UCS-66(a) [see also Note (1) in Figure UCS-66.2], shall not exceed that given in (-a) or (-b) below:*
> >
> > > *(-a) 1/2 in. (13 mm) for materials listed in Curve A of Figure UCS-66.*

(-b) 1 in. (25 mm) for materials listed in Curve B, C, or D of Figure UCS-66.

(2) The completed vessel shall be hydrostatically tested per UG-99(b) or UG-99(c) or 27-4. Alternatively, the completed vessel may be pneumatically tested in accordance with 35-6. (Note: (f)(2) in the 2007 edition states: The completed vessel shall be hydrostatically tested per UG-99(b) or (c) or 27-4.)

(3) Design temperature is no warmer than 650°F (345°C) nor colder than -20°F (-29°C). Occasional operating temperatures colder than -20°F (-29°C) are acceptable when due to lower seasonal atmospheric temperature.

(4) The thermal or mechanical shock loadings are not a controlling design requirement. (See UG-22.)

(5) Cyclical loading is not a controlling design requirement. (See UG-22.)

Paragraph UG-22 – Loadings in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC lists loadings to be considered in designing a pressure vessel.

Figure UCS-66, which is the same in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC, presents four separate nonlinear plots (A, B, C, and D) of minimum design metal temperature vs nominal thicknesses up to 6 in. Each plot represents exemptions from impact testing for a group of carbon and low alloy steels that conform to materials specifications included within the scope of the four nonlinear plots as defined in the general notes. Figures UCS-66M presents corresponding plots based on metric units. Tabular values for Figures UCS-66 and UCS-66M are provided in Table UCS-66 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. However, as Figures UCS-66 and UCS-66M show, impact testing is required for all carbon and low alloy steels with a MDMT below -55°F and -48°C, respectively.

Toughness requirements specified in Paragraph UG-84 for materials listed in Table UCS-23 – Carbon and Low Alloy Steel and Table UHT-23 – Ferritic Steels with Tensile Properties Enhanced by Heat Treatment are the same in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC.

Toughness Requirements for High Alloy Steels

Part UHA in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC specifies requirements for pressure vessels constructed of high alloy steels. Paragraph UHA-11*(a)* states all materials subject to stress due to pressure shall conform to one of the specifications given in Section II and shall be limited to those listed in Table UHA-23 – High Alloy Steel except as otherwise provided in *(b)* and UG-4.

Toughness requirements for materials listed in Table UHA-23 are specified in Paragraph UG-84 Charpy Impact Tests in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. Paragraphs UG-84*(c)(4)(-b)* state that for Table UHA-23 materials, all requirements of UHA-51 shall apply. Paragraph UHA-51 in 2021 editions of Section VIII, Division 1 of the ASME BPVC states:

> *Impact tests, as prescribed in (a), shall be performed on materials listed in Table UHA-23 for all combinations of materials and MDMTs except as exempted in (d), (e), (f), (g), (h), or (i). Impact testing is required for UNS S17400 materials. Impact tests are not required where the maximum obtainable Charpy specimen has a width along the notch less than 0.099 in. (2.5 mm). As an alternative method to impact tests, ASTM E1820 J_{IC} tests are allowed when the MDMT is colder than -320°F (-196°C). See Figures JJ-1.2-1 through JJ-1.2-5 for flowchart illustrations of impact testing requirements.*

The impact testing requirement for UNS S17400 materials and the alternative method to impact tests, which are allowed in the 2021 editions of Section VIII, Division 1 of the ASME BPVC, were added to Paragraph UHA-51 in 2007 editions of Section VIII, Division 1 of the ASME BPVC.

Flowcharts that illustrate toughness testing requirements and exemptions from toughness testing by the rules of Paragraph UHA-51*(d)*, *(e)*, *(f)*, *(g)*, *(h)*, and *(i)* are provided in Nonmandatory Appendix JJ, Figures JJ-1.2-1 through JJ-1.2-5 in the 2021 editions of Section VIII, Division 1 of the ASME BPVC. These figures cover the following.

- Figure JJ-1.2-1 titled: *Austenitic Stainless Steel Base Metal and HAZ Toughness Testing Requirements*
- Figure JJ-1.2-2 titled: *Welding Procedure Qualification with Toughness Testing Requirements for Austenitic Stainless Steel*
- Figure JJ-1.2-3 titled: *Welding Consumable Pre-Use Testing Requirements for Austenitic Stainless Steel*
- Figure JJ-1.2-4 titled: *Production Toughness Testing Requirements for Austenitic Stainless Steel*
- Figure JJ-1.2-5 titled: *Austenitic-Ferritic Duplex, Ferritic Chromium, and Martensitic Stainless Steel Toughness Testing Requirements*

Toughness requirements specified in Paragraph UG-84 for materials listed in listed in Table UHA-23 – High Alloy Steel are the same in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC.

Toughness Requirements for Nonferrous Materials

Part UNF in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC specifies requirements for pressure vessels constructed of nonferrous materials. Paragraph UNF-5*(a)* states that all nonferrous materials subject to stress due to pressure shall conform to one of the specifications given in Section II and shall be limited to those listed in Tables UNF-23.1 through UNF-23.5 except as otherwise provided in Paragraphs UG-10 and UG-11.

Rules specified in Paragraph UNF-65 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC state:

> *The materials listed in Tables UNF-23.1 through UNF-23.5, together with deposited weld metal within the range of composition for material in that Table, do not undergo a marked drop in impact resistance at subzero temperature. Therefore, no additional requirements are provided for wrought aluminum alloys when they are used at temperatures down to -452°F (-269°C); for copper and copper alloys, nickel and nickel alloys, and cast aluminum alloys when they are used at temperatures down to -325°F (-198°C); and for titanium or zirconium and their alloys used at temperatures down to -75°F (-59°C). The materials listed in Tables UNF-23.1 through UNF-23.5 may be used at lower temperatures than those specified herein and for other weld metal compositions provided the user satisfies himself by suitable test results such as determinations of tensile elongation and sharp-notch tensile strength (compared to unnotched tensile strength) that the material has suitable ductility at the design temperature.*

Toughness requirements specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC for nonferrous materials are the same.

Toughness Requirements for Cr–Mo Steels

Rules for Cr–Mo steels with additional requirements for welding and heat treatment are specified in Paragraph 31-5 in Mandatory Appendix 31 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. These rules state that the minimum toughness requirements for base metal, weld metal, and heat affected zone, after exposure to the simulated postweld heat treatment Condition B, must be an impact energy equal to or greater than 40 ft-lb based on an average for three specimens with a 35 ft-lb minimum limit for one specimen in the set of three specimens for full size Charpy V-notch, transvers specimens tested at the MDMT. Condition B is defined as follows: Condition B: Temperature must be no higher than the actual minimum vessel-portion temperature, plus 25°F (15°C). Time at temperature must be no more than 120% of the actual hold time of the vessel-portion exposed to the minimum vessel-portion temperature.

Toughness requirements specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC for Cr-Mo Steels are the same.

4.1.3.3 Toughness Requirements in Section VIII, Division 2

Rules in Part 3 – Materials Requirements, Paragraph 3.4 – Supplemental Requirements for Cr–Mo Steels in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC cover the various Cr-Mo steels listed in Table 3.1. Paragraph 3.4.5 – Toughness Requirements in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC states:

> *The minimum toughness requirements for base metal, weld metal, and heat-affected zone, after exposure to the simulated postweld heat treatment Condition B, are shown in Table 3.3. If the material specification or other parts of this Division have more demanding toughness requirements, they shall be met.*

Rules in Part 3 Materials Requirements, Paragraph 3.11 – Material Toughness Requirements in the 2007 and 2021 specify separate requirements for the following material groups.

- *(a)* Toughness requirements for materials listed in Table 3-A.1 (carbon and low alloy steel materials except bolting materials) are given in Paragraph 3.11.2.
- *(b)* Toughness requirements for materials listed in Table 3-A.2 (quenched and tempered steels with enhanced tensile properties) are given in Paragraph 3.11.3.
- *(c)* Toughness requirements for materials listed in Table 3-A.3 (high alloy steels except bolting materials) are given in Paragraph 3.11.4.
- *(d)* Toughness requirements for materials listed in Table 3-A.4 through 3-A.7 (nonferrous alloys) are given in Paragraph 3.11.5.
- *(e)* Toughness requirements for all bolting materials are given in Paragraph 3.11.6.

Toughness Requirements for Carbon and Low Alloy Steel Materials Except Bolting Materials Listed in Table 3-A.1

Part 3, Paragraph 3.11.2 – Carbon and Low Alloy Steels Except Bolting in the 2021 edition of Section VIII, Division 2 of the ASME BPVC specifies toughness requirements for carbon and low alloy steel listed in Table 3-A.1. According to these requirements, impact tests must be performed on carbon and low alloy materials listed in Table 3-A.1 for all combinations of materials and MDMTs except as exempted by Paragraph 3.11.2.3, 3.11.2.4, 3.11.2.5, or 3.11.2.8. According to Paragraph 3.11.2.1*(b)*, when impact testing is necessary, the following toughness values are required.

(1) *If the specified minimum tensile strength is less than 655 MPa (95 ksi), then the required minimum energy for all specimen sizes shall be that shown in Figure 3.3 and Figure 3.4 for vessel parts not subject to postweld heat treatment (PWHT) and vessel parts subject to PWHT or nonwelded parts, respectively, multiplied by the ratio of the actual specimen width along the notch to the width of a full-size specimen, except as otherwise provided in 3.11.7.2(b).*

(2) *If the specified minimum tensile strength is greater than or equal to 655 MPa (95 ksi), then the minimum lateral expansion (See Figure 3.5) opposite the notch for all specimen sizes shall not be less than the values shown in Figure 3.6.*

Figure 3.3 in the 2007 and 2021editions of Section VIII, Division 2 of the ASME BPVC, which depict the same plots, presents Charpy V-notch impact test requirements for full-size specimens for carbon and low alloy steels as a function of the minimum specified yield strength for parts not subject to PWHT. Tabulated values plotted in Figure 3.3 are listed in Table 4.2 of this report.

Table 4.2 Charpy V-notch (ft-lb) for parts not subject to PWHT

Thickness	Specified Minimum Yield Strength, ksi				
	30	38	50	65	80
0.25	20	20	20	20	20
0.375	20	20	20	20	23
0.50	20	20	20	20	27
0.625	20	20	20	21	32
0.75	20	20	20	25	37
1	20	20	20	33	46
1.25	20	20	25	39	53
1.5	20	20	30	45	60

Figure 3.4 in the 2007 and 2021editions of Section VIII, Division 2 of the ASME BPVC, which depict the same plots, presents Charpy V-notch impact test requirements for full-size specimens for carbon and low alloy steels as a function of the minimum specified yield strength for parts subject to PWHT or nonwelded parts. Tabulated values plotted in Figure 3.4 are listed in Table 4.3 of this report.

Table 4.3 Charpy V-notch (ft-lb) for parts subject to PWHT

Thickness	Specified Minimum Yield Strength, ksi				
	30	38	50	65	80
0.25	20	20	20	20	20
0.375	20	20	20	20	20
0.5	20	20	20	20	20
0.625	20	20	20	20	20
0.75	20	20	20	20	20
1	20	20	20	20	20
1.25	20	20	20	20	25
1.5	20	20	20	20	30
1.75	20	20	20	23	35
2	20	20	20	26	38
2.25	20	20	20	29	41
2.5	20	20	20	32	44
2.75	20	20	21	34	47
3	20	20	23	36	50
3.25	20	20	25	38	52

Thickness	Specified Minimum Yield Strength, ksi				
	30	**38**	**50**	**65**	**80**
3.5	20	20	26	40	54
3.75	20	20	27	42	56
4	20	20	28	43	58
4.25	20	20	29	44	59
4.5	20	20	29	45	60
4.75	20	20	30	45	60
5	20	20	30	45	61
5.25	20	20	30	45	61
5.5	20	20	30	45	61
5.75	20	20	30	45	61
6	20	20	30	45	61
6.25	20	20	30	45	61
6.5	20	20	30	45	61
6.75	20	20	30	45	61
7	20	20	30	45	61

Figure 3.6 is a plot of the minimum lateral expansion (mils) opposite the notch for all Charpy V-notch specimen sizes versus maximum nominal thickness of material for weld (in.). However, the plot in Figure 3.6 in the 2007 edition is different from the plot in Figure 3.6 in the 2021 edition of Section VIII, Division 2 of the ASME BPVC.

The plot for Figure 3.6 in the 2007 edition of Section VIII, Division 2 of the ASME BPVC, which is the same as the plot in Figure UHT-6.1 in 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC, consists of three straight line segments as follows:

Segment 1 For thicknesses ranging from 0.0 to 1.25 in. the minimum lateral expansion equals 15 mils.

Segment 2 For thicknesses ranging from 1.0 to 2.0 in. the minimum lateral expansion varies linearly from 15 mils at 1.25 in. to 25 mils at 3.0 in.

Segment 3 For thicknesses ranging from 3.0 to 4.0 in. the minimum lateral expansion equals 25 mils.

The plot for Figure 3.6 in the 2021 edition of Section VIII, Division 2 of the ASME BPVC consists of three straight line segments as follows:

Segment 1 For thicknesses ranging from 0.0 to 1.0 in. the minimum lateral expansion equals 20 mils.

Segment 2 For thicknesses ranging from 1.0 to 2.0 in. the minimum lateral expansion varies linearly from 20 mils at 1.0 in. to 32 mils at 2.0 in.

Segment 3 For thicknesses ranging from 2.0 to 4.0 in. the minimum lateral expansion equals 32 mils.

The minimum lateral expansion values permitted in the 2021 edition for materials listed in Table 3-A.1 – Carbon and Low Alloy Steel Materials Except Bolting Materials are approximately 30% greater than the minimum lateral expansion values permitted in the 2007 edition of Section VIII, Division 2 of the ASME BPVC. Consequently, toughness requirements in the 2021 edition of Section VIII, Division 2 of the ASME BPVC for materials listed in Table 3-A.1 are more stringent than those in the 2007 edition for materials listed in Table 3-A.1. The explanation for this change, which was adopted in the 2008 Addenda, follows.

In the 2007 editions the toughness rules for high-strength steels with ultimate tensile strength greater than 95 ksi was the same as was published in the prior edition, even though the allowable design stress for these materials can be higher by a factor of 1.25. Analytical work was performed to assess the toughness requirements of these materials, and as a result of this work the lateral expansion shown in Figures 3.6 and 3.6M were revised resulting in an average increase of approximately 30%

Exemptions from impact testing are based on:

- the MDMT, thickness, and material specification are specified in Part 3, Paragraph 3.11.2.3 in the 2021 edition of Section VIII, Division 2 of the ASME BPVC.
- material specification and product form are specified in Part 3, Paragraph 3.11.2.4 in the 2021 Edition of Section VIII, Division 2 of the ASME BPVC.
- design stress values are specified in Part 3, Paragraph 3.11.2.5 in the 2021 edition of Section VIII, Division 2 of the ASME BPVC.

Part 3, Paragraph 3.11.2.8 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC provides an alternative to impact testing. According to rules specified in Paragraph 3.11.2.8 for this alternative, the MDMT may be established using a fracture mechanics approach. The fracture mechanics procedures must be in accordance with API 579-1/ASME FFS *Fitness-For-Service* [9], Part 9, Level 2 or Level 3. Rules for conducting fracture mechanic evaluations are provided in Part 5 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. Paragraph 5.11 – Fracture Mechanics Evaluations states that fracture mechanics evaluations performed to determine the MDMT in accordance with 3.11.2.8 shall be in accordance with API/ASME FFS-1. Residual stresses resulting from welding shall be considered along with primary and secondary stresses in all fracture mechanics calculations.

Toughness Requirements for Quenched and Tempered Steels with Enhanced Tensile Properties Listed in Table 3-A.2

Part 3, Paragraph 3.11.3 – Quenched and Tempered Steels in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC specifies toughness requirements for quenched and tempered steels listed in Table 3-A.2. According to requirements specified in Paragraph 3.11.3.1*(a)*, all quenched and tempered steels listed in Table 3-A.2 must be subjected to Charpy V-notch testing and in Paragraph 3.11.3.2*(d)*, the minimum lateral expansion shall be in accordance with 3.11.2.1*(b)(2)* which states:

> *If the specified minimum tensile strength is greater than or equal to 655 MPa (95 ksi), then the minimum lateral expansion (See Figure 3.5) opposite the notch for all specimen sizes must not be less than the values shown in Figure 3.6.* (Note: Refer to the discussions above concerning differences in Figure 3.6 between the 2007 and 2021 editions of the of Section VIII, Division 2 of the ASME BPVC.)

Additional requirements are provided in Paragraph 3.11.3.3 – Drop-Weight Tests in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. Paragraph 3.11.3.3*(a)* states that when the MDMT is colder than -29°C (-20°F), drop-weight tests as defined by ASTM E208 – Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels, shall be made on all materials listed in Table 3-A.2. The three exceptions to these requirements are provided in Part 3, Paragraph 3.11.3.3(*a*). Paragraph 3.11.3.3*(d)* Required Test Results states that each of the two test specimens shall meet the "no-break" criterion, as defined by ASTM E208, at the test temperature.

Toughness Requirements for High Alloy Steels Except Bolting Materials Listed in Table 3-A.3

Part 3, Paragraph 3.11.4 – High Alloy Steels Except Bolting in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC specifies toughness requirements for quenched and tempered steels listed in Table 3-A.3. Requirements specified in Paragraph 3.11.4.1 state:

> *(a) Impact tests shall be performed on high alloy materials listed in Table 3-A.3 for all combinations of materials and MDMTs except as exempted by Paragraph 3.11.4.3 or 3.11.4.5. Impact testing is also required for UNS S17400 materials. Impact tests shall be made from sets of three specimens: one set from the base metal, one set from the weld metal, and one set from the heat affected zone (HAZ). Specimens shall be subjected to the same thermal treatments as the part or vessel that the specimens represent.*
>
> *(b) When the MDMT is −196°C (−320°F) and warmer, impact tests shall be conducted at the MDMT or colder, and the minimum lateral expansion opposite the notch shall be no less than 0.38 mm (0.015 in.) for MDMTs of −196°C (−320°F) and warmer.*
>
> *(c) When the MDMT is colder than −196°C (−320°F), production welding processes shall be limited to shielded metal arc welding (SMAW), gas metal arc welding (GMAW), submerged arc welding (SAW), plasma arc welding (PAW), and gas tungsten arc welding (GTAW). Each heat, lot, or batch of filler metal and filler metal/flux combination shall be pre-use tested as required by 3.11.4.5(d)(1) through 3.11.4.5(d)(3).*

Toughness requirements specified in Part 3, Paragraph 3.11.4.1*(b)* and *(c)* are the same in the 2007 and 2021 edition of Section VIII, Division 2 of the ASME BPVC.

Toughness Requirements for Nonferrous Alloys Listed in Table 3-A.4 through 3-A.7

Part 3, Paragraph 3.11.5 – Nonferrous Alloys in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC provides requirements for nonferrous materials. Paragraph 3.11.5.1 states that nonferrous materials listed in Tables 3-A.4 through 3-A.7, together with deposited weld metal within the range of composition for material in that Table, do not undergo a marked drop in impact resistance at subzero temperature. Therefore, additional requirements are not specified for:

> *(a)* Wrought aluminum alloys when they are used at temperature down to -269°C (-452°F);
>
> *(b)* Copper and copper alloys, nickel and nickel alloys, and cast aluminum alloys when they are used at temperatures down to −198°C (−325°F); and
>
> *(c)* Titanium or zirconium and their alloys used at temperatures down to -59°C (-75°F).

Toughness requirements specified in Part 3, Paragraph 3.11.5.1 are the same in the 2007 and 2021 edition of Section VIII, Division 2 of the ASME BPVC.

Toughness Requirements for Bolting Materials

Part 3, Paragraph 3.11.6 – Bolting Materials in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC specifies toughness requirements for bolting materials.

Paragraph 3.11.6.1 – Bolting Materials for Use with Flanges Designed to 4.16 states:

> *(a) Impact tests are not required for bolting materials listed in Tables 3.4, 3.5, 3.6, and 3.7 when used at MDMTs equal to or warmer than those shown in these Tables.*
>
> *(b) Bolting materials to be used for colder temperatures than those shown in Tables-3.4 through 3.7 shall conform to SA-320, except that the toughness criterion shall be Charpy V-notch with acceptance criteria in accordance with 3.11.2 or 3.11.4, as applicable.*

Paragraph 3.11.6.2 – Bolting Materials for Use with Flanges Designed to Part 5 of this Division states: Impact testing is required for the ferrous bolting materials listed in Table 3-A.11 for use with flanges designed in accordance with Part 5 of this Division. The average for three Charpy V-notch impact specimens shall be at least 41 J (30 ft-lb), with the minimum value for any individual specimen not less than 34 J (25 ft-lb).

Toughness requirements specified in Part 3, Paragraph 3.11.6 are the same in the 2007 and 2021 edition of Section VIII, Division 2 of the ASME BPVC.

Toughness Requirements for Cr–Mo Steels

Supplemental Requirements for Cr–Mo Steels are provided in Part 3, Paragraph 3.4 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. According to Paragraph 3.4.1.1, the rules in Paragraph 3.4 include supplemental requirements for fabrication and testing for Cr-Mo steels. The materials and appropriate specifications covered by this paragraph are listed in Table 3.1.

Toughness requirements for Cr–Mo steels are specified in Part 3, Paragraph 3.4.5 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. According to requirements in Paragraph 3.4.5, the minimum toughness requirements for base metal, weld metal, and heat-affected zone, after exposure to the simulated postweld heat treatment Condition B, are shown in Table 3.3. If the material specification or other parts of this Division have more demanding toughness requirements, they shall be met.

According to Table 3.3 – Toughness Requirements for 2.25Cr–1Mo Materials, impact energy is equal to or greater than 40 ft-lb based on an average for three specimens with a 35 ft-lb minimum limit for one specimen in the set of three specimens for full size Charpy V-notch, transvers specimens tested at the MDMT.

Condition B is defined in Paragraph 3.4.3.1*(b)* as follows. Condition B – Temperature shall be no higher than the actual minimum vessel-portion temperature, plus 14°C (25°F). Time at temperature shall be no more than 120% of the actual hold time of the vessel portion exposed to the minimum vessel-portion temperature.

Toughness requirements specified in Table 3.3 are the same in the 2007 and 2021 edition of Section VIII, Division 2 of the ASME BPVC.

4.1.4 Stress Rupture and Creep Deformation

Boiler and pressure vessel materials that are in service above a certain temperature undergo continuing deformation (creep) at a rate that is strongly influenced by both stress and temperature. The temperature at which creep occurs varies with the alloy composition. To prevent excessive deformation and possible premature rupture it is necessary to limit the allowable stresses by additional criteria on creep-rate and stress-rupture. In the creep range of temperatures, these criteria may limit the allowable stress to substantially lower values than those suggested by the usual factors on short time tensile and yield strengths.

Historically, the official ASME position has been that a design in the creep range has no implied maximum duration. When setting allowable stress limits, ASME uses the average and minimum 100,000 hr. stress rupture strengths of a material and also considers a conservative estimate of 10^{-7}/hr. for the creep (strain) rate.

Additional information about creep rupture properties associated with materials used in ASME BPVC construction is provided in Nonmandatory Appendix A, Paragraph A-200 – Metallurgical Changes that can Occur in Service in the 2021 edition of Section II, Part D of the ASME BPVC.

4.1.4.1 Stress Rupture and Creep Deformation Requirements in Section I and Section VIII, Division 1

Criteria for establishing allowable stresses at temperatures in the range where creep and stress rupture strength govern are provided in Section II, Part D of the ASME BPVC as discussed in Sect. 4.4 of this report. It is important to note that the allowable stresses specified in the 2007 and 2021 editions of Section II, Part D of the ASME BPVC at temperatures in the range where creep and stress rupture strength govern are the same. Satisfactory empirical limits for creep-rate and stress-rupture have been established and are used in the 2007 and 2027 editions of Section I and Section VIII, Division 1 of the ASME BPVC [6].

4.1.4.2 Stress Rupture and Creep Deformation Requirements in Section VIII, Division 2

Creep behavior complicates the detailed stress analysis because the distribution of stress will vary with time as well as with the applied loads. The difficulties are particularly noticeable under cyclic loading. It has not yet been possible to formulate complete design criteria and rules in the creep range. Therefore, rules specified in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC are restricted to temperatures at which creep will not be significant. This is achieved by limiting the tabulated allowable stress intensities to below the temperature of creep behavior. The ASME Subgroup on Elevated Temperature is studying this problem [6].

4.1.5 Plastic Instability – Incremental Collapse

Ratcheting is defined as a progressive incremental inelastic deformation or strain that can occur in a component subjected to variations of mechanical stress, thermal stress, or both. Ratcheting is produced by a sustained load acting over the full cross section of a component, in combination with a strain controlled cyclic load or temperature distribution that is alternately applied and removed. Ratcheting results in cyclic straining of the material, which can cause failure by fatigue and at the same time produces cyclic incremental deformation, which may ultimately lead to collapse.

4.1.5.1 Plastic Instability and Incremental Collapse in Section I

Boilers that are designed and fabricated in accordance with rule specified in Section I of the ASME BPVC are generally not subjected to cyclic loading. In addition, rules specified in the 2007 and 2021 editions of Section I of the ASME BPVC do not:

- require calculation of thermal stresses and do not provide allowable values for them,
- require the detailed calculation and classification of all stresses and the application of different stress limits to different classes of stress, or
- consider the possibility of fatigue failure [6].

Instead, rules in the 2007 and 2021 editions of Section I of the ASME BPVC provide equations for minimum wall thickness based on the maximum stress theory discussed in Sect. 4.5.1 of this report. Therefore, no plastic instability and incremental collapse requirements associated with ratcheting are specified in either the 2007 or 2021 edition of Section I of the ASME BPVC.

4.1.5.2 Plastic Instability and Incremental Collapse in Section VIII, Division 1

As discussed in Sect. 4.2.2 of this report, Paragraph U-2*(a)* in the 2021 edition of Section VIII, Division 1 of the ASME BPVC states that the user or his designated agent (See Nonmandatory Appendix NN – Guidance to the Responsibilities of the User and Designated Agent) shall establish the design requirements for pressure vessels, taking into consideration factors associated with normal operation, such other conditions as startup and shutdown, and abnormal conditions which may become a governing design consideration (See UG-22 – Loadings). When cyclic service is a design consideration, the user or his designated agent must state if a fatigue analysis is required.

Rules specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC do not:

- require calculation of thermal stresses and do not provide allowable values for them,
- require the detailed calculation and classification of all stresses and the application of different stress limits to different classes of stress, or
- consider the possibility of fatigue failure [6].

Instead, rules in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC provide equations for minimum wall thickness based on the maximum stress theory discussed in Sect. 4.5.1 of this report. Consequently, no plastic instability and incremental collapse requirements associated with ratcheting are specified in either the 2007 or 2021 edition of Section VIII, Division 1 of the ASME BPVC.

4.1.5.3 Plastic Instability and Incremental Collapse in Section VIII, Division 2

Rules for protection against failure from cyclic loading are specified in Part 5, Paragraph 5.5 – Protection Against Failure from Cyclic Loading in the 2007 and 2021 edition of Section VIII, Division 2 of the ASME BPVC. A fatigue evaluation must be performed if the component is subject to cyclic operation. The evaluation for fatigue is made on the basis of the number of applied cycles of a stress or strain range at a point in the component. The allowable number of cycles should be adequate for the specified number of cycles as given in the User's Design Specification.

Under certain combinations of steady-state and cyclic loadings there is a possibility of ratcheting. A rigorous evaluation of ratcheting normally requires an elastic–plastic analysis of the component; however, under a limited number of loading conditions, an approximate analysis can be used based on the results of an elastic stress analysis.

Rules for ratcheting assessments are specified in Part 5, Paragraphs 5.5.6 – Ratcheting Assessment — Elastic Stress Analysis and 5.5.7 – Ratcheting Assessment — Elastic–Plastic Stress Analysis in the 2007 and 2021editions of Section VIII, Division 2 of the ASME BPVC. Protection against ratcheting must be considered for all operating loads listed in the User's Design Specification and must be performed even if the fatigue screening criteria are satisfied (see 5.5.2). Protection against ratcheting is satisfied if one of the following three conditions is met:

1. The loading results in only primary stresses without any cyclic secondary stresses.
2. Elastic Stress Analysis Criteria – Protection against ratcheting is demonstrated by satisfying the rules of 5.5.6.
3. Elastic–Plastic Stress Analysis Criteria – Protection against ratcheting is demonstrated by satisfying the rules of 5.5.7.

Rules for Elastic Stress Analysis provided in Paragraph 5.5.6 are subdivided into the following four categories.

- Elastic Ratcheting Analysis Method
- Simplified Elastic–Plastic Analysis
- Thermal Stress Ratcheting Assessment
- Progressive Distortion of Non-Integral Connections

Rules for Elastic-Plastic Stress Analysis provided in Paragraph 5.5.7 involves application, removal, and re-application of the applied loadings. If protection against ratcheting is satisfied, it may be assumed that progression of the stress–strain hysteresis loop along the strain axis cannot be sustained with cycles and that the hysteresis loop will stabilize. A separate check for plastic shakedown to alternating plasticity is not required. The following assessment procedure can be used to evaluate protection against ratcheting using elastic–plastic analysis.

The rules for ratcheting assessments specified in Part 5, Paragraphs 5.5.6 and 5.5.7 are the same in the 2007 and 2021editions of Section VIII, Division 2 of the ASME BPVC.

4.1.6 Fatigue

Fatigue is the weakening of a material caused by repeatedly applied loads. It is the progressive and localized material degradation that occurs when a component is subjected to cyclic loading. If the loads are above a certain threshold, microscopic cracks will begin to form at stress concentrations such as square holes or sharp corners. Eventually the crack will reach a critical size, propagate, and cause the component to fracture. Avoidance of discontinuities that increase local stresses will increase the fatigue life of a component subjected to cyclic loading.

There are two basic forms of fatigue that can adversely affect a boiler or pressure vessel. High-cycle fatigue (HCF) is characterized by low amplitude high frequency elastic strains. Low-cycle fatigue (LCF) is characterized by high amplitude low frequency plastic strains. The primary difference between HCF and LCF is the fact that the former involves little or no plastic action, whereas failure in a few thousand cycles can be produced only by strains in excess of the yield strain. In the plastic region, large changes in strain can be produced by small changes in stress.

The ASME BPVC establishes fatigue margins based on two considerations: (1) a factor of twenty on the number of cycles, and (2) a factor of two on stress. Studies of fatigue test data show that 10,000 cycles are the approximate border between LCF and HCF and a factor of twenty on the number of cycles has little effect at a high number of cycles. Consequently, a factor on stress was introduced as a margin at the higher number of cycles. A factor of two on stress gives approximately the same margin as a factor of twenty on cycles [6].

4.1.6.1 Fatigue Requirements in Section I

Boilers that are designed and fabricated in accordance with rule specified in Section I of the ASME BPVC are generally not subjected to cyclic loading. In addition, rules specified in the 2007 and 2021editions of Section I of the ASME BPVC do not:

- require calculation of thermal stresses and do not provide allowable values for them,
- require the detailed calculation and classification of all stresses and the application of different stress limits to different classes of stress, or
- consider the possibility of fatigue failure [6].

Instead, rules in the 2007 and 2021editions of Section I of the ASME BPVC provide equations for minimum wall thickness based on the maximum stress theory discussed in Sect. 4.5.1 of this report. Therefore, no rules for fatigue are specified in either the 2007 or the 2021 edition of Section I of the ASME BPVC.

4.1.6.2 Fatigue Requirements in Section VIII, Division 1

As discussed in Sect. 4.2.2 of this report, Paragraph U-2*(a)* in the 2021 edition of Section VIII, Division 1 of the ASME BPVC states that the user or his designated agent (See Nonmandatory Appendix NN – Guidance to the Responsibilities of the User and Designated Agent) shall establish the design requirements for pressure vessels, taking into consideration factors associated with normal operation, such other conditions as startup and shutdown, and abnormal conditions which may become a governing design consideration (See UG-22 – Loadings). When cyclic service is a design consideration, the user or his designated agent must state if a fatigue analysis is required.

Rules specified in the 2007 and 2021editions of Section VIII, Division 1 of the ASME BPVC do not:

- require calculation of thermal stresses and do not provide allowable values for them,
- require the detailed calculation and classification of all stresses and the application of different stress limits to different classes of stress, or
- consider the possibility of fatigue failure [6].

Instead, rules in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC provide equations for minimum wall thickness based on the maximum stress theory discussed in Sect. 4.5.1 of this report. Consequently, no rules for fatigue are specified in either the 2007 or the 2021 edition of Section VIII, Division 1 of the ASME BPVC.

4.1.6.3 Fatigue Requirements in Section VIII, Division 2

Rules specified in Part 4 – Design by Rule Requirements, Paragraph 4.1.1.4 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC state:

> *A screening criterion shall be applied to all pressure vessel parts designed in accordance with this Division to determine if a fatigue analysis is required. The fatigue screening criterion shall be performed in accordance with 5.5.2. If the results of this screening indicate that a fatigue analysis is required, then the analysis shall be performed in accordance with 5.5.2. If the allowable stress at the design temperature is governed by time-dependent properties, then a fatigue screening analysis based on experience with comparable equipment shall be satisfied (See 5.5.2.2).*

Rules for performing a fatigue screening are specified in Paragraph 5.5.2 – Screening Criteria for Fatigue Analysis in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. These criteria are subdivided into the following four categories.

- Fatigue Analysis Screening Based on Experience with Comparable Equipment
- Fatigue Analysis Screening, Method A
- Fatigue Analysis Screening, Method B

Rules for performing a fatigue evaluation are specified in the following Paragraphs in the 2007 and 2021editions of Section VIII, Division 2 of the ASME BPVC.

- Paragraph 5.5.3 – Fatigue Assessment – Elastic Stress Analysis and Equivalent Stresses. In this method, an effective total equivalent stress amplitude is used to evaluate the fatigue damage for results obtained from a linear elastic stress analysis.
- Paragraph 5.5.4 – Fatigue Assessment – Elastic Plastic Stress Analysis and Equivalent Strains. In this method, the effective strain range is used to evaluate the fatigue damage for results obtained from an elastic–plastic stress analysis.
- Paragraph 5.5.5 – Fatigue Assessment of Welds – Elastic Analysis and Structural Stress. In this method, an equivalent structural stress range parameter is used to evaluate the fatigue damage for results obtained from a linear elastic stress analysis.

The rules for performing a fatigue screening and fatigue evaluation are the same in the 2007 and 2021editions of Section VIII, Division 2 of the ASME BPVC.

4.1.7 Stress Corrosion and Corrosion Fatigue

Corrosion is a surface phenomenon that exhibits the gradual destruction of metals by chemical or electrochemical reactions with their environment. There are many types of corrosion that can cause deterioration of boiler and pressure vessel components. Two common types of corrosion that can adversely affect the integrity of a boiler or pressure vessel include stress corrosion cracking and corrosion fatigue.

Stress corrosion cracking (SCC) is the growth of crack formation in a corrosive environment and is highly chemically specific in that certain alloys are likely to undergo SCC only when exposed to a small number of chemical environments. The chemical environment that causes SCC for a given alloy is often one which is only mildly corrosive to the metal otherwise. The specific environment is of crucial importance, and only small concentrations of certain highly active chemicals are needed to produce catastrophic cracking, often leading to devastating and unexpected failure. Metal components with severe SCC can appear bright and shiny, while being filled with microscopic cracks. These cracks can lead to unexpected sudden failure of normally ductile metals subjected to a tensile stress. Additional information about SCC associated with materials used in ASME BPVC construction is provided in Nonmandatory Appendix A, Paragraph A-701 in the 2021 edition of Section II, Part D of the ASME BPVC.

Corrosion fatigue is the mechanical degradation of a material under the joint action of corrosion and cyclic loading. Since corrosion-fatigue cracks initiate at a metal’s surface, surface treatments like plating, cladding, nitriding, and shot peening can improve the materials’ resistance to corrosion fatigue. However, corrosion fatigue only occurs when the metal is under tensile stress. The rate of fatigue crack growth is enhanced by corrosion. Additional information about corrosion fatigue associated with materials used in ASME BPVC construction is provided in Nonmandatory Appendix A, Paragraph A-605 in the 2021 edition of Section II, Part D of the ASME BPVC.

Users or their designated agents are responsible for assuring that the materials used for construction of boilers and pressure vessels are suitable for the intended service conditions with respect to mechanical properties, resistance to corrosion, erosion, oxidation, and other damage mechanisms anticipated during service life. Protection against environmental conditions such as corrosion is the responsibility of the designer when included in the design basis. This protection is normally accomplished by selecting corrosion resistant materials and adding a corrosion allowance to the required minimum thickness of a component. The corrosion allowance does not need to be the same for all parts of a boiler or pressure vessel. However, the ASME BPVC does not provide mandatory requirements for corrosion allowances.

4.1.7.1 Corrosion Requirements in Section I

Concerns for corrosion of certain materials used for boiler construction are identified in the following statement in Paragraph PG-5.5 in the 2007 and 2021 editions of Section I of the ASME BPVC.

> *Austenitic alloys are susceptible to intergranular corrosion and stress corrosion cracking when used in boiler applications in water-wetted service. Factors that affect the sensitivity to these metallurgical phenomena are applied or residual stress and water chemistry. Susceptibility to attack is usually enhanced by using the material in a stressed condition with a concentration of corrosive agents (e.g., chlorides, caustic, or reduced sulfur species). For successful operation in water environments, residual and applied stresses must be minimized and careful attention must be paid to continuous control of water chemistry.*

However, the 2007 and 2021 editions of Section I of the ASME BPVC do not include rules that specifically govern corrosion allowances.

4.1.7.2 Corrosion Requirements in Section VIII, Division 1

Rules for corrosion are specified in Paragraph UG-25 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. These rules state:

> *The user or his designated agent must specify corrosion allowances other than those required by the rules of this Division. Where corrosion allowances are not provided, this fact shall be indicated on the Data Report.*

In addition,

> *Vessels or parts of vessels subject to thinning by corrosion, erosion, or mechanical abrasion shall have provision made for the desired life of the vessel by a suitable increase in the thickness of the material over that determined by the design formulas, or by using some other suitable method of protection.*

The 2021 edition of Section VIII, Division 1 of the ASME BPVC includes Nonmandatory Appendix E – Suggested Good Practice Regarding Corrosion Allowance.

4.1.7.3 Corrosion Requirements in Section VIII, Division 2

Rules specified in Part 4, Paragraph 4.1.4.2 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC state:

> *The term corrosion allowance as used in this Division is representative of loss of metal by corrosion, erosion, mechanical abrasion, or other environmental effects and shall be accounted for in the design of vessels or parts when specified in the User's Design Specification.*

Requirements in Part 2 – Responsibilities and Duties, Paragraph 2.2.3.1*(f)* – Design Fatigue Life in the 2021 edition of Section VIII, Division 2 of the ASME BPVC states that a User's Design Specification shall include corrosion fatigue. If corrosion fatigue is anticipated, a factor should be chosen on the basis of experience or testing, by which the calculated design fatigue cycles (fatigue strength) should be reduced to compensate for the corrosion.

A discussion of screening criterion for determining if a fatigue analysis is required is presented in Sect. 4.1.6.3 of this report.

4.2 DESIGN BASIS

According to rules specified in the ASME BPVC, users are responsible for establishing the design basis for a boiler or pressure vessel. These rules vary from one Section and edition of the ASME BPVC to another. Requirements in Section I and Section VIII, Division 1 of the ASME BPVC do not explicitly consider the effects of combined stress or give detailed methods for combining stresses. However, Section VIII, Division 2 of the ASME BPVC provides specific guidelines for stresses, how they are combined, and allowable stresses for categories of combined stresses.

4.2.1 Design Basis Requirements in Section I

Design requirements for boiler components with multiple design conditions are provided in Paragraph PG-21.4 in the 2021 edition of Section I of the ASME BPVC. This paragraph, which is not included in the 2007 edition of Section I in the ASME BPVC, states that components with multiple design conditions may be designed considering the coincident pressures and temperatures if all of the following conditions are met.

1. The component shall be designed for the most severe condition of coincident pressure and temperature expected to be sustained during operation that results in the greatest calculated thickness for the pressure part and that will not exceed the maximum temperature, or the maximum allowable stress permitted in Section II, Part D for the material.
2. The design requirements of this Section must be met for each design condition (coincident pressure and temperature).
3. The maximum allowable working pressure (MAWP) selected for the part shall be sufficiently in excess of the highest pressure of the multiple design conditions to permit satisfactory boiler operation without operation of the overpressure protection device(s). Each design condition (coincident pressure and temperature) shall be reported on the Manufacturer's Data Report.

In addition, Paragraph PG-22.1 in the 2007 and 2021 editions of Section I of the ASME BPVC states:

> *Stresses due to hydrostatic head must be taken into account in determining the minimum thickness required unless noted otherwise. This Section does not fully address additional loadings other than those from working pressure or static head. Consideration must be given to such additional loadings.*

Nonmandatory Appendix D – Design Guidelines for Corrosion, Erosion, and Steam Oxidation of Boiler Tubes is included in the 2021 editions of Section I of the ASME BPVC. Paragraph D-1 – Introduction states that this Appendix provides an overview of guidelines for boiler design engineers and others aimed at minimization of the effects of fireside corrosion, particle impact erosion and steam-side oxidation on boiler tubing and other components of coal-fired boilers. Gas- and oil-fired boiler wastage are excluded.

4.2.2 User's Design Requirements in Section VIII, Division 1

Paragraph U-2*(a)* in the 2021 edition of Section VIII, Division 1 of the ASME BPVC states that the user or his designated agent (See Nonmandatory Appendix NN – Guidance to the Responsibilities of the User and Designated Agent) shall establish the design requirements for pressure vessels, taking into consideration factors associated with normal operation, such other conditions as startup and shutdown, and abnormal conditions which may become a governing design consideration (See UG-22 – Loadings).

Paragraph U-2*(a)* further states that such consideration shall include but shall not be limited to the following:

(1) the need for corrosion allowances.

(2) the definition of lethal services. For example, see UW-2(a).

(3) the need for postweld heat treatment beyond the requirements of this Division and dependent on service conditions.

(4) for pressure vessels in which steam is generated, or water is heated [see U-1*(g)* and U-1*(h)*], the need for piping, valves, instruments, and fittings to perform the functions covered by Section I, PG-59 through PG-61.

(5) the degree of nondestructive examination(s) and the selection of applicable acceptance standards when such examinations are beyond the requirements of this Division. (This consideration is not required in the Paragraph U-2*(a)* in the 2007 edition.)

Sample UDS forms and guidance on their preparation are found in Nonmandatory Appendix KK – Guide for Preparing User's Design Requirements. This sample form might not be applicable to all pressure vessels that may be constructed in accordance with this Division. The user is cautioned that input from the Manufacturer may be necessary for completion of this form.

Guidance for the responsibilities of the user and designated agent is provided in Nonmandatory Appendix NN – Guidance to the Responsibilities of the User and Designated Agent in the 2021 edition of Section VIII, Division 1 of the ASME BPVC. Nonmandatory Appendix NN provides a directory for locating the specific Code-assigned responsibilities and other considerations assigned to the user or his designated agent as applicable to the pressure vessel under consideration. These responsibilities and considerations are grouped into 11 categories as defined in NN-6*(a)*, and the Code paragraphs relevant to each category are detailed in Tables NN-6-1 through NN-6-11.

4.2.3 User's Design Specification Requirements in Section VIII, Division 2

Rules specified in Paragraph 2.2.1 in Part 2 – Responsibilities and Duties in the 2021 edition of Section VIII, Division 2 of the ASME BPVC states that it is the responsibility of the user or an agent acting on behalf of the user to provide a UDS for each pressure vessel to be constructed in accordance with this Division. The UDS shall contain sufficient detail to provide a complete basis for design and construction in accordance with this Division including design loads and load case combinations described in Paragraph 4.1.5.3 – Design Loads and Load Case Combinations.

According to requirements provided in Paragraph 4.1.5.3, all applicable loads and load case combinations shall be considered in the design to determine the minimum required wall thickness for a vessel part. The loads that shall be considered in the design shall include, but not be limited to, those shown in Table 4.1.1 – Design Loads and shall be included in the User's Design Specification. The load combinations that shall be considered shall include, but not be limited to, those shown in Table 4.1.2, except when a different recognized standard for wind loading is used. In that case, the User's Design Specification shall cite the Standard to be applied and provide suitable load factors if different from ASCE/SEI 7 [10]. The factors for wind loading, W, in Table 4.1.2, Design Load Combinations, are based on ASCE/SEI 7 wind maps and probability of occurrence. If a different recognized standard for earthquake loading is used, the User's Design Specification shall cite the Standard to be applied and provide suitable load factors if different from ASCE/SEI 7. Loads due to deflagration were not included in Table 4.1.1 in the 2007 edition but are included in Table 4.1.1 in the 2021 edition of Section VIII, Division 2 of the ASME BPVC. Guidance to accommodate loadings produced by deflagration are provided in Annex 4-D in the 2021 edition of Section VIII, Division 2 of the ASME BPVC. It is the user's responsibility to specify, or cause to be specified, the effective Code edition and vessel class to be used for construction.

Paragraph 2.2.3.1 states that the UDS shall include but not necessarily be limited to the following subject areas.

1. Installation site
2. Vessel identification
3. Vessel configuration and controlling dimensions
4. Design conditions
5. Operating conditions
6. Design fatigue life
7. Materials of construction
8. Loads and loads cases
9. Overpressure protection
10. Additional requirements discussed in Part 2 – Responsibilities and Duties, Paragraph 2.2.2.2 that may include requirements for NDE, heat treatments, types of weld joints, and information concerning erection loadings, etc. These additional design requirements could also include post-construction loads such as those associated with in-service pressure tests that may be required to comply with PHMSA pipeline safety regulations.

According to the following requirements specified in the 2021 edition of Section VIII, Division 2 of the ASME BPVC:

- Paragraph 2.2.2.1, the UDS for a Class 1 pressure vessel shall be certified by a Certifying Engineer meeting the requirements described in Annex 2-A – Guide for Certifying a User's Design Specification when the user provides the data in the USD required to perform a fatigue analysis.
- Paragraph 2.2.2.2, the UDS for a Class 2 pressure vessel shall be certified by a Certifying Engineer in accordance with Annex 2-A – Guide for Certifying a User's Design Specification.

When required by Paragraph 2.2.2.1 or 2.2.2.2, certification of the UDS requires the signature(s) of one or more Certifying Engineers with requisite experience and qualifications as defined in Annex 2-J – Qualifications and Requirements for Certifying Engineers and Designers.

As discussed on Sect. 2.3 of this report, the 2007 edition of Section VIII, Division 2 of the ASME BPVC states that one or more Professional Engineers, registered in one or more of the states of the United States of America or the provinces of Canada and experienced in pressure vessel design, shall certify that the UDS meets the requirements in Paragraph 2.2.2, and shall apply the Professional Engineer seal in accordance with the required procedures.

4.3 STRESS CATEGORIES

The ASME BPVC prescribes primary, secondary, and peak stress limits for boilers and pressure vessels to prevent the following modes of failure [6].

1. Bursting and gross distortion from a single application of pressure are prevented by the limits placed on primary stresses.
2. Progressive distortion is prevented by the limits placed on primary plus secondary stresses. These limits assure shake-down to elastic action after a few repetitions of the loading.
3. Fatigue failure is prevented by the limits placed on peak stresses.

Stress limit equations specified in the ASME BPVC are primarily a function of yield strength, but they also provide a design margin against plastic collapse caused by inelastic response as discussed in Sect. 4.8 of this report. These stress limits are used to establish MAWP, to define boundaries for pneumatic and hydrostatic pressure testing, and as the basis for overpressure protection limits. As discussed in Sect. 4 of this report, boiler and pressure vessel designers are responsible for understanding when primary, secondary, and peak stresses occur, and which equations must be applied.

4.3.1 Primary Stresses

A primary stress is a stress developed by the imposed loading which is necessary to satisfy the laws of equilibrium between external and internal forces and moments. Primary stresses are categorized as:

- General primary membrane stresses
- Primary bending stresses
- Local primary membrane stresses

The basic characteristic of a primary stress is that it is not self-limiting. If a primary 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. Primary stress limits for boilers and pressure vessels are intended to prevent gross distortion (i.e., plastic deformation) and bursting from a single application of pressure. The need for subdividing primary stress into membrane and bending categories is that limit design theory shows that the calculated value of a primary bending stress may be allowed to exceed the calculated value of a primary membrane stress [6]. A discussion of limit design theory is presented in Sect. 4.4 of this report.

4.3.2 Secondary Stresses

A secondary stress is a stress developed by the self-constraint of a component. It must satisfy an imposed strain pattern rather than being in equilibrium with an external load. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the discontinuity conditions or thermal expansions which cause secondary stress. Thermal stresses that can produce distortion of a component are categorized as secondary stresses.

4.3.3 Peak Stresses

A peak stress is 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 because it is a possible source of fatigue failure. Thermal stresses that result from almost complete suppression of the differential expansion, and thus cause no significant distortion, are categorized as peak stresses.

4.4 MAXIMUM ALLOWABLE DESIGN STRESSES

The ASME BPVC provides rules for establishing allowable stresses for ferrous and nonferrous metals and for bolting materials. As Table 2.2 in this report shown, different maximum allowable stress limits are prescribed for specific material types and temperature ranges. Maximum allowable stress limits have evolved over time and vary from one Section and edition of the ASME BPVC to another. The basis for establishing allowable stress values is explained in Mandatory Appendices 1, 2, and 10 in Section II, Part D in the 2021 edition of the ASME BPVC.

Alternative rules for establishing allowable design stresses in materials having higher allowable stresses at low temperature are provided in Part ULT of Section VIII, Division 1 of the ASME BPVC. Similar rules for materials having higher allowable stresses at low temperature are not provided in Section I or Section VIII, Division 2 of the ASME BPVC.

4.4.1 Basis for Establishing Allowable Stress Values in Tables 1A and 1B

Criteria for establishing allowable stress values for Tables 1A and 1B are provided in Mandatory Appendix 1, Table 1-100 in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC. Tables 1A and 1B provides allowable stresses for materials permitted for Section I and Section VIII, Division 1 construction. At temperatures below the range where creep and stress rupture strength govern the selection of stresses, the maximum allowable stress value is the lowest of the following:

1-100*(a)(1)* the specified minimum tensile strength at room temperature divided by 3.5

1-100*(a)(2)* the tensile strength at temperature divided by 3.5

1-100*(a)(3)* two-thirds of the specified minimum yield strength at room temperature

1-100*(a)(4)* two-thirds of the yield strength at temperature

At temperatures in the range where creep and stress rupture strength govern the selection of stresses, the maximum allowable stress value for all materials is established by the Committee not to exceed the lowest of the following:

1-100*(b)(1)* 100% of the average stress to produce a creep rate of 0.01%/1,000 hr.

1-100*(b)(2)* $100F_{\text{avg}}$% of the average stress to cause rupture at the end of 100,000 hr.

1-100*(b)(3)* 80% of the minimum stress to cause rupture at the end of 100,000 hr.

A comparison of maximum allowable stress values in Section II, Part D, Subpart 1, Table 1A and Table 1B in the 2007 and 2021 editions of the ASME BPVC is provided in Table 4.4 and Table 4.5 in this report. Table 4.4 provides maximum allowable stress values for ferrous and nonferrous wrought and cast materials. Table 4.5 provides maximum allowable stress values for ferrous and nonferrous welded pipes and tubes.

Table 4.4 Criteria in Tables 1A and 1B for establishing allowable stress values for ferrous and nonferrous for wrought and cast materials

Criteria Paragraph 1-100	Section II, Part D, Mandatory Appendix 1, 2007 Edition	Section II, Part D, Mandatory Appendix 1, 2021 Edition
1-100 *(a)*(*1*)	$\frac{S_T}{3.5}$ all temperatures	$\frac{S_T}{3.5}$ all temperatures
1-100*(a)*(*2*) see Note 1	$\frac{1.1}{3.5}S_T R_T$ above room temperature	$\frac{1.1}{3.5}S_T R_T$ above room temperature
1-100*(a)*(*3*)	$\frac{2}{3}S_Y$ all temperatures	$\frac{2}{3}S_Y$ all temperatures
1-100*(a)*(*4*) see Notes 1and 2	$\frac{2}{3}S_Y R_Y$ or 0.9 $S_Y R_Y$ above room temperature	$\frac{2}{3}S_Y R_Y$ or 0.9 $S_Y R_Y$ above room temperature
1-100*(b)*(*1*)	1.0 S_C above room temperature	1.0 S_C above room temperature
1-100(*b*)(*2*)	$F_{\text{avg}}S_{R\,\text{avg}}$ above room temperature	$F_{\text{avg}}S_{R\,\text{avg}}$ above room temperature
1-100*(b)(3)*	0.8 $S_{R\,\text{min}}$	0.8 $S_{R\,\text{min}}$

	above room temperature	above room temperature

where:

F_{avg} = multiplier applied to average stress for rupture in 100,000 hr. At 1500°F and below, F_{avg} = 0.67. Above 1500°F, it is determined from the slope of the log time-to-rupture versus log stress plot at 100,000 hr such that log [F_{avg}] = 1/n, but F_{avg} may not exceed 0.67.

n = a negative number equal to Δ log time-to-rupture divided by Δ log stress at 100,000 hr.

R_T = ratio of the average temperature dependent trend curve value of tensile strength to the room temperature tensile strength.

R_Y = ratio of the average temperature dependent trend curve value of yield strength to the room temperature yield strength.

S_C = average stress to produce a creep rate of 0.01%/1,000 hr.

$S_{R\ avg}$ = average stress to cause rupture at the end of 100,000 hr.

$S_{R\ min}$ = minimum stress to cause rupture at the end of 100,000 hr.

S_T = specified minimum tensile strength at room temperature.

S_y = specified minimum yield strength at room temperature.

Notes:

1. The Committee considers the yield strength at temperature to be $S_Y R_Y$, and the tensile strength at temperature to be 1.1 $S_T R_T$.
2. Two sets of allowable stress values may be provided for austenitic stainless steels in Table 1A; and nickel alloys, copper alloys, and cobalt alloys in Table 1B; having an S_Y/S_T ratio less than 0.625. The lower values are not specifically identified by a footnote. These lower values do not exceed two-thirds of the yield strength at temperature. The higher alternative allowable stresses are identified by a footnote. These higher stresses may exceed two-thirds but do not exceed 90% of the yield strength at temperature. The higher values should be used only where slightly higher deformation is not in itself objectionable. These higher stresses are not recommended for the design of flanges or for other strain-sensitive applications.

Table 4.5 Criteria in Tables 1A and 1B for establishing allowable stress values for ferrous and nonferrous welded pipe and tubing

Criteria Paragraph 1-100	Section II, Part D, Mandatory Appendix 1, 2007 Edition	Section II, Part D, Mandatory Appendix 1, 2021 Edition
1-100*(a)*(*1*)	$\frac{0.85\ S_T}{3.5}$ all temperatures	$\frac{0.85\ S_T}{3.5}$ all temperatures
1-100*(a)*(*2*) see Note 1	$\frac{0.85 \times 1.1}{3.5} S_T R_T$ above room temperature	$\frac{0.85 \times 1.1}{3.5} S_T R_T$ above room temperature
1-100*(a)*(*3*)	$\frac{2}{3} \times 0.85\ S_Y$ all temperatures	$\frac{2}{3} \times 0.85\ S_Y$ all temperatures
1-100*(a)*(*4*) see Notes 1 and 2	$\frac{2}{3} \times 0.85\ S_Y R_Y$ or $0.9 \times 0.85 \times S_Y R_Y$ above room temperature	$\frac{2}{3} \times 0.85\ S_Y R_Y$ or $0.9 \times 0.85 \times S_Y R_Y$ above room temperature
1-100(b)(*1*)	0.85 S_C above room temperature	0.85 S_C above room temperature
1-100(*b*)(*2*)	$F_{avg} \times 0.85 \times S_{R\ avg}$ above room temperature	$F_{avg} \times 0.85 \times S_{R\ avg}$ above room temperature

1-100*(b)(3)*	0.8 x 0.85 $S_{R\ \mathrm{min}}$ above room temperature	0.8 x 0.85 $S_{R\ \mathrm{min}}$ above room temperature

where:

F_{avg} = multiplier applied to average stress for rupture in 100,000 hr. At 1500°F and below, F_{avg} = 0.67. Above 1500°F, it is determined from the slope of the log time-to-rupture versus log stress plot at 100,000 hr such that log [F_{avg}] = 1/n, but F_{avg} may not exceed 0.67.

n = a negative number equal to Δ log time-to-rupture divided by Δ log stress at 100,000 hr.

R_T = ratio of the average temperature dependent trend curve value of tensile strength to the room temperature tensile strength.

R_Y = ratio of the average temperature dependent trend curve value of yield strength to the room temperature yield strength.

S_C = average stress to produce a creep rate of 0.01%/1,000 hr.

$S_{R\ \mathrm{avg}}$ = average stress to cause rupture at the end of 100,000 hr.

$S_{R\ \mathrm{min}}$ = minimum stress to cause rupture at the end of 100,000 hr.

S_T = specified minimum tensile strength at room temperature.

S_y = specified minimum yield strength at room temperature.

Notes:

1. The Committee considers the yield strength at temperature to be $S_Y R_Y$, and the tensile strength at temperature to be 1.1 $S_T R_T$.
2. Two sets of allowable stress values may be provided for austenitic stainless steels in Table 1A; and nickel alloys, copper alloys, and cobalt alloys in Table 1B; having an S_Y/S_T ratio less than 0.625. The lower values are not specifically identified by a footnote. These lower values do not exceed two-thirds of the yield strength at temperature. The higher alternative allowable stresses are identified by a footnote. These higher stresses may exceed two-thirds but do not exceed 90% of the yield strength at temperature. The higher values should be used only where slightly higher deformation is not in itself objectionable. These higher stresses are not recommended for the design of flanges or for other strain-sensitive applications.

4.4.2 Basis for Establishing Design Stress Intensity Values in Tables 2A and 2B

Criteria for establishing design stress intensity values in Table 2A and 2B are provided in Mandatory Appendix 2, Table 2-100*(a)* in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC. Tables 2A and 2B provide design stress intensity values for materials permitted for Section VIII, Division 2, Class 1 construction (See Annex 3-A – Allowable Design Stresses in Section VIII, Division 2 in the 2021 edition of the ASME BPVC). Paragraph 2-110 – Criteria for Materials Other Than Bolting: Tables 2A and 2B states that the design stress intensity values at any temperature are no larger than the least of the following:

- 2-110*(a)* one-third of the specified minimum tensile strength at room temperature
- 2-110*(b)* one-third of the tensile strength at temperature
- 2-110*(c)* two-thirds of the specified minimum yield strength at room temperature
- 2-110*(d)* two-thirds of the yield strength at temperature, except that for austenitic stainless steels, nickel alloys, copper alloys, and cobalt alloys having an S_Y/S_T ratio less than 0.625, as indicated in Tables 2A and 2B, this value may be as large as 90% of the yield strength at temperature (but never more than two-thirds of the specified minimum yield strength)

A comparison of design stress intensity values in Section II, Part D, Subpart 1, Table 2A and Table 2B in the 2007 and 2021 editions of the ASME BPVC is provided in Table 4.6 for ferrous and nonferrous wrought and cast materials and Table 4.7 for ferrous and nonferrous welded pipes and tubes in this report.

Table 4.6 Criteria in Tables 2A and 2B for establishing design stress intensity values for ferrous and nonferrous for wrought and cast materials other than bolting

Criteria Paragraph 2-110	Section II, Part D, Mandatory Appendix 1, 2007 Edition	Section II, Part D, Mandatory Appendix 1, 2021 Edition
2-110*(a)*	$\frac{S_T}{3}$ all temperatures	$\frac{S_T}{3}$ all temperatures
2-110*(b)* see Note 1	$\frac{1.1}{3} S_T R_T$ above room temperature	$\frac{1.1}{3} S_T R_T$ above room temperature
2-110*(c)*	$\frac{2}{3} S_Y$ all temperatures	$\frac{2}{3} S_Y$ all temperatures
2-110*(d)* see Notes 1 and 2	$\frac{2}{3} S_Y R_Y$ or 0.9 $S_Y R_Y$ above room temperature	$\frac{2}{3} S_Y R_Y$ or 0.9 $S_Y R_Y$ above room temperature

where:

F_{avg} = multiplier applied to average stress for rupture in 100,000 hr. At 1500°F and below, F_{avg} = 0.67. Above 1500°F, it is determined from the slope of the log time-to-rupture versus log stress plot at 100,000 hr such that log [F_{avg}] = 1/n, but F_{avg} may not exceed 0.67.

n = a negative number equal to Δ log time-to-rupture divided by Δ log stress at 100,000 hr.

R_T= ratio of the average temperature dependent trend curve value of tensile strength to the room temperature tensile strength

R_Y= ratio of the average temperature dependent trend curve value of yield strength to the room temperature yield strength

S_C= average stress to produce a creep rate of 0.01%/1,000 hr.

$S_{R\,avg}$ = average stress to cause rupture at the end of 100,000 hr.

$S_{R\,min}$ = minimum stress to cause rupture at the end of 100,000 hr.

S_T = specified minimum tensile strength at room temperature.

S_y = specified minimum yield strength at room temperature.

Notes:

1. The Committee considers the yield strength at temperature to be $S_Y R_Y$, and the tensile strength at temperature to be 1.1 $S_T R_T$.
2. For austenitic stainless steels, nickel alloys, copper alloys, and cobalt alloys having an S_Y/S_T ratio less than 0.625, the design stress intensity values in Tables 2A and 2B may exceed two-thirds and may be as high as 90% of the yield strength at temperature.

Table 4.7 Criteria in Tables 2A and 2B for establishing design stress intensity values for ferrous and nonferrous for welded pipe and tubing other than bolting

Criteria Paragraph 2-110	Section II, Part D, Mandatory Appendix 1, 2007 Edition	Section II, Part D, Mandatory Appendix 1, 2021 Edition
2-110*(a)*	$\frac{0.85\ S_T}{3}$ all temperatures	$\frac{0.85\ S_T}{3}$ all temperatures
2-110*(b)* see Note 1	$\frac{1.1 \times 0.85}{3} S_T R_T$	$\frac{1.1 \times 0.85}{3} S_T R_T$

	above room temperature	above room temperature
2-110*(c)*	$\frac{2}{3}$ x 0.85 x S_Y all temperatures	$\frac{2}{3}$ x 0.85 x S_Y all temperatures
2-110*(d)* see Notes 1 and 2	$\frac{2}{3}$ x 0.85 x $S_Y R_Y$ or 0.9 x 0.85 x $S_Y R_Y$ above room temperature	$\frac{2}{3}$ x 0.85 x $S_Y R_Y$ or 0.9 x 0.85 x $S_Y R_Y$ above room temperature

where:

F_{avg} = multiplier applied to average stress for rupture in 100,000 hr. At 1500°F and below, F_{avg} = 0.67. Above 1500°F, it is determined from the slope of the log time-to-rupture versus log stress plot at 100,000 hr such that log [F_{avg}] = 1/n, but F_{avg} may not exceed 0.67.

n = a negative number equal to Δ log time-to-rupture divided by Δ log stress at 100,000 hr.

R_T = ratio of the average temperature dependent trend curve value of tensile strength to the room temperature tensile strength.

R_Y = ratio of the average temperature dependent trend curve value of yield strength to the room temperature yield strength.

S_C = average stress to produce a creep rate of 0.01%/1,000 hr.

$S_{R\text{ avg}}$ = average stress to cause rupture at the end of 100,000 hr.

$S_{R\text{ min}}$ = minimum stress to cause rupture at the end of 100,000 hr.

S_T = specified minimum tensile strength at room temperature.

S_y = specified minimum yield strength at room temperature.

Notes:

1. The Committee considers the yield strength at temperature to be $S_Y R_Y$, and the tensile strength at temperature to be 1.1 $S_T R_T$.
2. For austenitic stainless steels, nickel alloys, copper alloys, and cobalt alloys having an S_Y/S_T ratio less than 0.625, the design stress intensity values in Tables 2A and 2B may exceed two-thirds and may be as high as 90% of the yield strength at temperature.

4.4.3 Basis for Establishing Allowable Stress Values in Table 3

Criteria for establishing allowable stress values in Table 3 are provided in Mandatory Appendix 2, Table 2-120*(a)* in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC. Table 3 provides allowable stress values for bolting materials for use in Section VIII, Division 1 and Section VIII, Division 2 (using Part 4.16 of Section VIII, Division 2) construction. Allowable stress values at any temperature are provided in Table 3 for materials whose strength has not been enhanced by heat treatment or by strain hardening and materials whose strength has been enhanced by heat treatment or by strain hardening. The allowable stress value shown at any temperature in Table 3 for materials whose strength has not been enhanced by heat treatment or by strain hardening is the least of the following:

- 2-120*(a)(1)* one-fourth of the specified minimum tensile strength at room temperature
- 2-120*(a)(2)* one-fourth of the tensile strength at temperature
- 2-120*(a)(3)* two-thirds of the specified minimum yield strength at room temperature
- 2-120*(a)(4)* two-thirds of the yield strength at temperature

The allowable stress value shown at any temperature in Table 3 for materials whose strength has been enhanced by heat treatment or by strain hardening is the least of the following:

- 2-120*(b)(1)* one-fifth of the specified minimum tensile strength at room temperature
- 2-120*(b)(2)* one-fourth of the tensile strength at temperature

2-120*(b)(3)* one-fourth of the specified minimum yield strength at room temperature

2-120*(b)(4)* two-thirds of the yield strength at temperature

At temperatures in the range where creep and stress rupture strength govern the selection of stresses, the maximum allowable stress value for all materials is established by the Committee not to exceed the lowest of the following:

2-120*(d)(1)* 100% of the average stress to produce a creep rate of 0.01%/1,000 hr.

2-120*(d)(2)* $100F_{avg}$% of the average stress to cause rupture at the end of 100,000 hr.

2-120*(d)(3)* 80% of the minimum stress to cause rupture at the end of 100,000 hr.

A comparison of allowable stress values in Section II, Part D, Subpart 1, Table 3 in the 2007 and 2021 editions of the ASME BPVC is provided in Table 4.8 and Table 4.9 of this report. Table 4.8 provides allowable stress values for annealed ferrous and nonferrous bolting materials and products. Table 4.9 provides allowable stress values for ferrous and nonferrous bolting materials and products with strength enhanced by heat treatment or strain hardening.

Table 4.8 Criteria in Table 3 for establishing allowable stress values for annealed ferrous and nonferrous bolting

Criteria Paragraph 2.120	Section II, Part D, Mandatory Appendix 2, 2007 Edition	Section II, Part D, Mandatory Appendix 2, 2021 Edition
2-120*(a)*(*1*)	$\frac{S_T}{4}$ all temperatures	$\frac{S_T}{4}$ all temperatures
2-120*(a)*(*2*) see Note 1	$\frac{1.1}{4}S_T R_T$ above room temperature	$\frac{1.1}{4}S_T R_T$ above room temperature
2-120*(a)*(*3*)	$\frac{2}{3}S_Y$ all temperatures	$\frac{2}{3}S_Y$ all temperatures
2-120*(a)*(*4*) see Note 1	$\frac{2}{3}S_Y R_Y$ above room temperature	$\frac{2}{3}S_Y R_Y$ above room temperature
2-120*(d)*(*1*)	1.0 S_C above room temperature	1.0 S_C above room temperature
2-120*(d)(2)*	$F_{avg}\ S_{R\ avg}$ above room temperature	$F_{avg}\ S_{R\ avg}$ above room temperature
2-120*(d)(3)*	0.8 $S_{R\ min}$ above room temperature	0.8 $S_{R\ min}$ above room temperature

where:

F_{avg} = multiplier applied to average stress for rupture in 100,000 hr. At 1500°F and below, F_{avg} = 0.67. Above 1500°F, it is determined from the slope of the log time-to-rupture versus log stress plot at 100,000 hr such that log [F_{avg}] = 1/n, but F_{avg} may not exceed 0.67.

n = a negative number equal to Δ log time-to-rupture divided by Δ log stress at 100,000 hr.

R_T = ratio of the average temperature dependent trend curve value of tensile strength to the room temperature tensile strength.

R_Y = ratio of the average temperature dependent trend curve value of yield strength to the room temperature yield strength.

S_C = average stress to produce a creep rate of 0.01%/1,000 hr.

$S_{R\ avg}$ = average stress to cause rupture at the end of 100,000 hr.

$S_{R\ min}$ = minimum stress to cause rupture at the end of 100,000 hr.

S_T = specified minimum tensile strength at room temperature.

S_y = specified minimum yield strength at room temperature.

Notes:

1. The Committee considers the yield strength at temperature to be $S_Y R_Y$, and the tensile strength at temperature to be 1.1 $S_T R_T$.

Table 4.9 Criteria in Table 3 for establishing allowable stress values for ferrous and nonferrous bolting with strength enhanced by heat treatment of strain hardening

Criteria Paragraph 2-120 see Note 2	Section II, Part D, Mandatory Appendix 1, 2007 Edition	Section II, Part D, Mandatory Appendix 1, 2021 Edition
2-120*(b)*(*1*)	$\frac{S_T}{5}$ all temperatures	$\frac{S_T}{5}$ all temperatures
2-120*(b)*(*2*) see Note 1	$\frac{1.1}{4} S_T R_T$ above room temperature	$\frac{1.1}{4} S_T R_T$ above room temperature
2-120*(b)*(*3*)	$\frac{S_Y}{4}$ all temperatures	$\frac{S_Y}{4}$ all temperatures
2-120*(b)*(*4*) see Note 1	$\frac{2}{3} S_Y R_Y$ above room temperature	$\frac{2}{3} S_Y R_Y$ above room temperature
2-120*(d)*(*1*)	1.0 S_C above room temperature	1.0 S_C above room temperature
2-120*(d)(2)*	$F_{avg}\ S_{R\ avg}$ above room temperature	$F_{avg}\ S_{R\ avg}$ above room temperature
2-120*(d)(3)*	0.8 $S_{R\ min}$ above room temperature	0.8 $S_{R\ min}$ above room temperature

where:

F_{avg} = multiplier applied to average stress for rupture in 100,000 hr. At 1500°F and below, F_{avg} = 0.67. Above 1500°F, it is determined from the slope of the log time-to-rupture versus log stress plot at 100,000 hr such that log [F_{avg}] = 1/n, but F_{avg} may not exceed 0.67.

n = a negative number equal to Δ log time-to-rupture divided by Δ log stress at 100,000 hr.

R_T = ratio of the average temperature dependent trend curve value of tensile strength to the room temperature tensile strength.

R_Y = ratio of the average temperature dependent trend curve value of yield strength to the room temperature yield strength.

S_C = average stress to produce a creep rate of 0.01%/1,000 hr.

$S_{R\ avg}$ = average stress to cause rupture at the end of 100,000 hr.

$S_{R\ min}$ = minimum stress to cause rupture at the end of 100,000 hr.

S_T = specified minimum tensile strength at room temperature.

S_y = specified minimum yield strength at room temperature.

Notes:

1. The Committee considers the yield strength at temperature to be $S_Y R_Y$, and the tensile strength at temperature to be 1.1 $S_T R_T$.
2. For materials whose strength has been enhanced by heat treatment or by strain hardening, the criteria shown shall govern unless the values are lower than for the annealed material, in which case the annealed values shall be used.

4.4.4 Basis for Establishing Design Stress Intensity Values in Table 4

Criteria for establishing design stress intensity values in Table 4 are provided in Mandatory Appendix 2, Table 2-130*(a)* in Section II, Part D of the 2007 and 2021 edition of the ASME BPVC. Table 4 provides design stress intensities for bolting materials used in Section VIII, Division 2 (using Part 5 and Annex 5.F of Section VIII, Division 2) construction. The allowable stress or design stress intensity values shown at any temperature in Table 4 is the least of the following:

(a) For materials whose strength has not been enhanced by heat treatment or strain hardening:
- *(1)* one-fourth of the specified minimum tensile strength at room temperature
- *(2)* one fourth of the tensile strength at temperature
- *(3)* two-thirds of the specified minimum yield strength at room temperature
- *(4)* two-thirds of the yield strength at temperature

(b) For materials whose strength has been enhanced by heat treatment or strain hardening:
- *(1)* one-third of the specified minimum yield strength at room temperature
- *(2)* one-third of the yield strength at temperature

A comparison of design stress intensity values in Section II, Part D, Subpart 1, Table 4 in the 2007 and 2021 editions of the ASME BPVC is provided in Table 4.10 and Table 4.11 of this report. Table 4.10 provides design stress intensity values for ferrous and nonferrous bolting with strength not enhanced by heat treatment or strain hardening. Table 4.11 provides design stress intensity values for ferrous and nonferrous bolting with strength enhanced by heat treatment or strain hardening.

Table 4.10 Criteria in Table 4 for establishing allowable stress or design stress intensity values for ferrous and nonferrous bolting with strength not enhanced by heat treatment or strain hardening

Criteria Paragraph 2-130	Section II, Part D, Mandatory Appendix 2, 2007 Edition	Section II, Part D, Mandatory Appendix, 2021 Edition
2-130*(a)(1)*	N/A	$\frac{S_T}{4}$ room temperature and below
2-130*(a)(2)* see Note 1	N/A	$\frac{1.1}{4} S_T R_T$ above room temperature
2-130*(a)(3)*	N/A	$\frac{2}{3} S_Y$ room temperature and below
2-130*(a)(4)* see Note 1	N/A	$\frac{2}{3} S_Y R_Y$ above room temperature

where:

N/A = not applicable

R_T =	ratio of the average temperature dependent trend curve value of tensile strength to the room temperature tensile strength
R_Y =	ratio of the average temperature dependent trend curve value of yield strength to the room temperature yield strength
S_T =	specified minimum tensile strength at room temperature.
S_y =	specified minimum yield strength at room temperature.

Notes:

1. The Committee considers the yield strength at temperature to be $S_Y R_Y$, and the tensile strength at temperature to be 1.1 $S_T R_T$.

Table 4.11 Criteria in Table 4 for establishing allowable stress or design stress intensity values for ferrous and nonferrous bolting with strength enhanced by heat treatment or strain hardening

Criteria Paragraph 2-130	Section II, Part D, Mandatory Appendix 2, 2007 Edition	Section II, Part D, Mandatory Appendix, 2021 Edition
2-130*(b)(1)*	$\frac{S_Y}{3}$ room temperature and below	$\frac{S_Y}{3}$ room temperature and below
2-130*(b)(2)* see Note 1	$\frac{S_Y R_Y}{3}$ above room temperature	$\frac{S_Y R_Y}{3}$ above room temperature

where:

R_Y =	ratio of the average temperature dependent trend curve value of yield strength to the room temperature yield strength
S_y =	specified minimum yield strength at room temperature.

Note:

1. The Committee considers the yield strength at temperature to be $S_Y R_Y$.

4.4.5 Basis for Establishing Allowable Stress Values in Table 5A and 5B

Criteria for establishing maximum allowable stress values for Tables 5A and 5B are provided in Section II, Mandatory Appendix 10, Table 10-100 in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC. Table 5A and Table 5B provide maximum allowable stress values for construction of Class 2 vessels in accordance with rules specified in Annex 3-A – Allowable Design Stresses in Section VIII, Division 2 in the 2021 edition of the ASME BPVC. Based on these criteria, at temperatures below the range where creep and stress rupture strength govern the selection of stresses, the maximum allowable stress value is the lowest of the following:

10-100*(a)(1)* the specified minimum tensile strength (S_T) at room temperature divided by 2.4

10-100*(a)(2)* the specified minimum yield strength (S_y) divided by 1.5

10-100*(a)(3)* the yield strength at temperature ($S_y R_y$) divided by 1.5, except for austenitic stainless steels, nickel alloys, copper alloys, and cobalt alloys

10-100*(a)(4)* for austenitic stainless steels, nickel alloys, copper alloys, and cobalt alloys having a specified minimum yield strength at room temperature, S_y, divided by the specified minimum tensile strength at room temperature, S_T, ratio (e.g., S_y/S_T) less than 0.625, higher stress values are established at temperatures where the short-time tensile properties govern, to permit use of these alloys where slightly greater deformation is acceptable. The stress values in this range exceed 66⅔%, but do not exceed 90%, of the yield strength at temperature, but never exceed two-thirds of the specified room-temperature minimum yield strength. These higher stress values are not recommended for the flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

At temperatures in the range where creep and stress rupture govern the selection of stresses, the maximum allowable stress value for all materials is established by the Committee not to exceed the lowest of the following:

10-100*(b)(1)* 100% of the average stress to produce a creep rate of 0.01%/1,000 hr.

10-100*(b)(2)* 100F_{avg}% of the average stress to cause rupture at the end of 100,000 hr.

10-100*(b)(3)* 80% of the minimum stress to cause rupture at the end of 100,000 hr.

A comparison of maximum allowable stress values in Section II, Part D, Subpart 1, Table 5A and Table 5B in the 2007 and 2021 editions of the ASME BPVC is provided in Tables 4.12 and Table 4.13 of this report. Maximum allowable stress values for all wrought and cast ferrous and nonferrous materials expect bolting, and for austenitic stainless steels, nickel alloys, copper alloys, and cobalt alloy product forms having an S_y/S_T ratio less than 0.625 are provided on Tables 4.11. Maximum allowable stress values for all wrought and cast austenitic stainless steels, nickel alloys, copper alloys, and cobalt alloy product forms having an S_y/S_T ratio less than 0.625 are provided on Tables 4.12.

Table 4.12 Criteria for establishing allowable stress values for Tables 5A and 5B for all wrought and cast ferrous and nonferrous materials expect bolting, austenitic stainless steels, nickel alloys, copper alloys, and cobalt alloys

Criteria Paragraph 10-100	Section II, Part D, Mandatory Appendix 10, 2007 Edition	Section II, Part D, Mandatory Appendix 10, 2021 Edition
10-100*(a)*(*1*)	$\frac{S_T}{2.4}$ all temperatures	$\frac{S_T}{2.4}$ all temperatures
10-100*(a)*(*2*)	$\frac{S_y}{1.5}$ below room temperature	$\frac{S_y}{1.5}$ below room temperature
10-100*(a)*(*3*) see Note 1	$\frac{R_y S_y}{1.5}$ room temperature and above	$\frac{R_y S_y}{1.5}$ room temperature and above
10-100(*a*)(*4*)	N/A	N/A
10-100*(b)*(*1*)	1.0 $S_{C\text{ avg}}$ room temperature and above	1.0 $S_{C\text{ avg}}$ room temperature and above
10-100(*b*)(*2*) and 10-100*(b)(3)*	$\min(F_{\text{avg}} S_{R\text{ avg}}, 0.8\, S_{R\text{ min}})$ room temperature and above	$\min(F_{\text{avg}} S_{R\text{ avg}}, 0.8\, S_{R\text{ min}})$ room temperature and above

where:

F_{avg} = multiplier applied to average stress for rupture in 100,000 hr. At 1500°F and below, F_{avg} = 0.67. Above 1500°F, it is determined from the slope of the log time-to-rupture versus log stress plot at 100,000 hr such that log [F_{avg}] = 1/n, but F_{avg} may not exceed 0.67.

n = a negative number equal to Δ log time-to-rupture divided by Δ log stress at 100,000 hr.

N/A = not applicable.

R_Y = ratio of the average temperature dependent trend curve value of yield strength to the room temperature yield strength.

$S_{C\text{ avg}}$ = average stress to produce a creep rate of 0.01%/1,000 hr.

$S_{R\text{ avg}}$ = average stress to cause rupture at the end of 100,000 hr.

$S_{R\text{ min}}$ = minimum stress to cause rupture at the end of 100,000 hr.

S_T = specified minimum tensile strength at room temperature.

S_y = specified minimum yield strength at room temperature.

Note:

1. The Committee considers the yield strength at temperature to be $S_Y R_Y$.

Table 4.13 Criteria for establishing allowable stress values for Tables 5A and 5B for all wrought and cast austenitic stainless steels, nickel alloys, copper alloys, and cobalt alloys

Criteria Paragraph 10-100	Section II, Part D, Mandatory Appendix 10, 2007 Edition	Section II, Part D, Mandatory Appendix 10, 2021 Edition
10-100*(a)*(*1*)	$\frac{S_T}{2.4}$ all temperatures	$\frac{S_T}{2.4}$ all temperatures
10-100*(a)*(*2*)	$\frac{S_y}{1.5}$ below room temperature	$\frac{S_y}{1.5}$ below room temperature
10-100*(a)*(*3*) see Note 1	$\frac{R_y S_y}{1.5}$ room temperature and above	$\frac{R_y S_y}{1.5}$ room temperature and above
10-100*(a)*(*4*) see Note 1	$\min\left(\frac{S_y}{1.5}, \frac{0.9\ S_y R_y}{1.0}\right)$ room temperature and above	$\min\left(\frac{S_y}{1.5}, \frac{0.9\ S_y R_y}{1.0}\right)$ room temperature and above
10-100*(b)*(*1*)	$1.0\ S_{C\text{ avg}}$ room temperature and above	$1.0\ S_{C\text{ avg}}$ room temperature and above
10-100(*b*)(*2*) and 10-100*(b)(3)*	$\min(F_{\text{avg}} S_{R\text{ avg}}, 0.8\ S_{R\text{ min}})$ room temperature and above	$\min(F_{\text{avg}} S_{R\text{ avg}}, 0.8\ S_{R\text{ min}})$ room temperature and above

where:

F_{avg} = multiplier applied to average stress for rupture in 100,000 hr. At 1500°F and below, F_{avg} = 0.67. Above 1500°F, it is determined from the slope of the log time-to-rupture versus log stress plot at 100,000 hr such that log [F_{avg}] = 1/n, but F_{avg} may not exceed 0.67.

n = a negative number equal to Δ log time-to-rupture divided by Δ log stress at 100,000 hr.

R_Y = ratio of the average temperature dependent trend curve value of yield strength to the room temperature yield strength

$S_{C\text{ avg}}$ = average stress to produce a creep rate of 0.01%/1,000 hr.

$S_{R\text{ avg}}$ = average stress to cause rupture at the end of 100,000 hr.

$S_{R\text{ min}}$ = minimum stress to cause rupture at the end of 100,000 hr.

S_T = specified minimum tensile strength at room temperature.

S_y = specified minimum yield strength at room temperature.

Note:

1. The Committee considers the yield strength at temperature to be $S_Y R_Y$.

4.4.6 Rules for Material Having Higher Allowable Stresses

Rules for materials having higher allowable stresses than those specified in Tables 1A and 1B in Section II of the ASME BPVC are provided in Part ULT – Alternative Rules for Pressure Vessels

Constructed of Materials Having Higher Allowable Stresses at Low Temperature and Mandatory Appendix 44 – Cold Stretching of Austenitic Stainless Steel Pressure Vessels.

4.4.6.1 Alternative Rules for Material Having a Higher Allowable Stress at Low Temperature

Alternative rules for maximum allowable stress values in tension for pressure vessels constructed using materials having higher allowable stresses at low temperature are tabulated in Part ULT of the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. Part ULT also includes rules that cover design, fabrication, inspection, testing, marking, reports, and overpressure protection. Paragraph ULT-5 – General in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC states that material covered by Part ULT subject to stress due to pressure shall conform to one of the specifications given in Section II and shall be limited to those listed in Table ULT-23. The title of Table ULT-23 is: V001 Maximum Allowable Stress Values in Tension for 5%, 7%, 8%, and 9% Nickel Steels; Types 304 and 316 Stainless Steels; and 5083 0 Aluminum Alloy at Cryogenic Temperatures for Welded and Nonwelded Construction. Maximum allowable stress values specified in Table ULT-23 are provided for temperatures between -320°F and 150°F (100°F in the 2007 edition).

Alternative rules in Part ULT for material having a higher allowable stress at low temperature in the 2007 edition of Section VIII, Division 1 of the ASME BPVC do not included maximum allowable stress values for Type 316 stainless steel.

4.4.6.2 Rules for Materials Having Higher Allowable Stresses for Cold Stretching of Austenitic Stainless Steel Pressure Vessels

Maximum design stress values for cold-stretched austenitic stainless steel pressure vessels are provided in Mandatory Appendix 44. Rules in Paragraph 44-4 – Materials and Allowable Design Stress state:

- The austenitic stainless steels listed in Table 44-4-1 are allowed in the vessel construction.
- The value of allowable design stress, S, in tension shall not exceed the value listed in Table 44-4-1.

All materials specified in Table 44-4-1 conform to specification SA-240/SA-240M, Type 304 and 316 stainless steels. Corresponding maximum design stress values for these materials are shown in Table 5.4 in this report. Further discussions about cold-stretched austenitic stainless steel pressure vessels are presented in Sect. 5.5 of this report.

Rules in Mandatory Appendix 44 for cold-stretched austenitic stainless steel pressure vessels are not included in the 2007 edition of Section VIII, Division 1 of the ASME BPVC.

4.4.7 Design Margin Against Bursting

As discussed in Sect 4.4.5 of this report, criterion 10-100*(a)(1)* in Mandatory Appendix 10 in Section II, Part D in the 2021 edition of the ASME BPVC limits the maximum allowable stress to the minimum tensile strength, S_T, at room temperature divided by 2.4. This criterion is applicable to materials permitted for construction of Class 2 vessels in accordance with rules specified in Section VIII, Division 2 in the 2021 edition of the ASME BPVC.

The factor 2.4 with respect to ultimate tensile strength is a design margin against bursting [8]. It is also intended to account for uncertainties in material properties, loading conditions, fabrication and welding, geometric shape, and the design approach that are difficult to quantify in terms of safety equivalency.

The bursting pressure of cylindrical and spherical shells can be predicted with reasonable accuracy if consideration is given to the strain hardening properties of the material [8]. However, there are no rules in the ASME BPVC for calculating burst pressure or for taking strain hardening properties into consideration. Therefore, it is impossible to quantify the magnitude of the design margin for bursting for a particular pressure vessel design configuration using ASME BPVC rules.

Experimental testing of pressure vessels was conducted at the University of Kansas in 1970s to develop a better understanding of the bursting mode of failure of pressure vessels designed and fabricated in accordance with rules specified in Section VIII, Division 2 of the ASME BPVC. The project included burst tests on pressure vessels fabricated from three materials with different strain hardening exponents (Type 304 stainless, SA-516 Gr. 70, and SA-517 Gr. F). These test results provide the basis for concluding that [8]:

> *Using the modified Svensson formula and the specified minimum tensile properties, the theoretical margins of safety for the University of Kansas test vessels (without sharp notches) designed to Section VIII, Division 2 rules, ranged from about 2.8 for the 304 stainless steel vessel (with high strain hardening exponent) to about 3.2 for the high strength, quenched and tempered steel SA-517 (with low strain hardening exponent).*

4.5 STRENGTH THEORIES

The stress state at any point in a boiler or pressure vessel is completely defined by the magnitudes and directions of the three principal stresses. When two or three of these stresses are different from zero, the proximity to yielding must be determined by means of a strength theory. The following strength theories are often used in engineering applications.

- maximum stress theory
- maximum shear stress theory (also known as the Tresca yield criterion)
- distortion energy theory (also known as the octahedral shear theory and the von Mises criterion)

The specific strength theory used as the basis for design rules specified in the ASME BPVC varies from one Construction Code to another.

The maximum stress theory states that the controlling stress is the largest of the three principal stresses. The Tresca criterion represents a critical value of the maximum shear stress in a material while the von Mises criterion represents a critical value of the distortional energy stored in a material. The maximum shear stress theory (Tresca) and the distortion energy theory (von Mises) are both much better than the maximum stress theory for predicting both yielding and fatigue failure in ductile metals. It is also important to note that rules specified in the ASME BPVC based on these strength theories are only applicable to homogenous materials with isotropic material properties.

4.5.1 Maximum Stress Theory

Equations specified in Section I and Section VIII, Division 1 of the ASME BPVC for determining wall thickness are, by implication, consistent with the maximum stress theory. For thin-walled cylindrical pressure components at locations that are remote from any discontinuities, the hoop stress is twice the axial stress and the radial stress on the inside is compressive and equal to the internal pressure, p. If the hoop stress is σ, the principal stresses are:

$$\sigma_1 = \sigma$$
$$\sigma_2 = \sigma/2$$
$$\sigma_3 = -p$$

According to the maximum stress theory, the controlling stress is σ, because it is the largest of the three principal stresses (provided $\sigma_1 > \sigma_3$).

4.5.2 Maximum Shear Stress Theory Using the Tresca Yield Criterion

Design rules specified in Section VIII, Division 2 in the ASME BPVC prior to the 2007 edition were consistent with the maximum shear stress theory. This statement is supported by the following text in Paragraph AD-140(*a*) in the 1992 edition of Section VIII, Division 2:

> *The theory of failure used in this Division is the maximum shear stress theory except in the case of some specially designed configurations, shapes, or design rules included as part of this Division.*

The maximum shear stress theory or Tresca theory of failure relates to the maximum shear stress of ductile materials. The maximum shear stress at a point is defined as one-half of the algebraic difference between the largest and the smallest of the three principal stresses. Thus, if the principal stresses are σ_1, σ_2, and σ_3, and $\sigma_1 > \sigma_2 > \sigma_3$, the maximum shear stress is given by $(\sigma_1 - \sigma_3)/2$. The maximum shear stress theory of failure states that yielding in a component occurs when the maximum shear stress reaches a value equal to the maximum shear stress at the yield point in a uniaxial tensile test. In the uniaxial tensile test, at yield, $\sigma_1 = S_y$, $\sigma_2 = 0$, and $\sigma_3 = 0$; therefore, the maximum shear stress is $S_y/2$, and yielding in the component occurs when:

$$(\sigma_1 - \sigma_3)/2 = S_y/2 \tag{4.1}$$

The term "stress intensity" is used to define a stress value that is twice the maximum shear stress and is equal to the largest algebraic difference between any two of the three principal stresses. Therefore, stress intensity is directly comparable to strength values found from uniaxial tensile tests.

Beginning with the 2007 edition of Section VIII, Division 2 of the ASME BPVC, the specified design-by-rule equations in Part 4 are based on a limit analysis using the Tresca yield criterion that has a three-dimensional yield or limit surface. This Tresca yield surface is defined by Equation {4.2} in the principal stress space.

$$f(\sigma_1, \sigma_2, \sigma_3) = \max(|\sigma_1 - \sigma_2|, |\sigma_2 - \sigma_3|, |\sigma_3 - \sigma_1|) = S_y \tag{4.2}$$

where:

S_y = yield strength in uniaxial tension

4.5.3 Distortion Energy Theory Using the von Mises Yield Criterion

Beginning with the 2007 edition of Section VIII, Division 2, Paragraph 5.2.2.1*(b)* in the 2007 and 2021 editions of the ASME BPVC state that the maximum distortion energy yield criterion shall be used to establish the equivalent stress. In this case, the equivalent stress is equal to the von Mises equivalent stress given by Equation {4.3}.

$$f(\sigma_1, \sigma_2, \sigma_3) = \left(1/\sqrt{2}\right)[(\sigma_1 - \sigma_2)^2, (\sigma_2 - \sigma_3)^2, (\sigma_3 - \sigma_1)^2]^{0.5} = S_y \tag{4.3}$$

where:

S_y = yield strength in uniaxial tension

Most experiments show that the distortion energy theory (von Mises) is more accurate than the shear theory (Tresca) because ductile materials behave closer to the von Mises yield criterion. However, the Tresca yield criterion gives a more conservative estimate on failure compared to the von Mises yield criterion. Under the same loading conditions, principal stresses determined using the Tresca yield criterion are approximately 15% more than the principal stresses determined using the von Mises yield criterion. Even though the maximum difference between the von Mises and Tresca yield criteria is only about 15%, this difference represents a systemic error (divergence) on the part of the Tresca yield criterion.

4.6 PRINCIPLES OF LIMIT DESIGN THEORY

The stress intensity limits specified in Section II of the ASME BPVC are based on application of limit design theory principles [6]. In this theory, materials are assumed to exhibit an elastic-perfectly plastic stress-strain relationship with no strain hardening as shown in Fig. 4.1 of this report. Allowable stresses based on perfect plasticity and limit design theory are considered by ASME to be a floor below which a boiler or pressure vessel constructed from any sufficiently ductile material will be safe. The actual strain-hardening properties of specific materials will give them an increased margin above this floor.

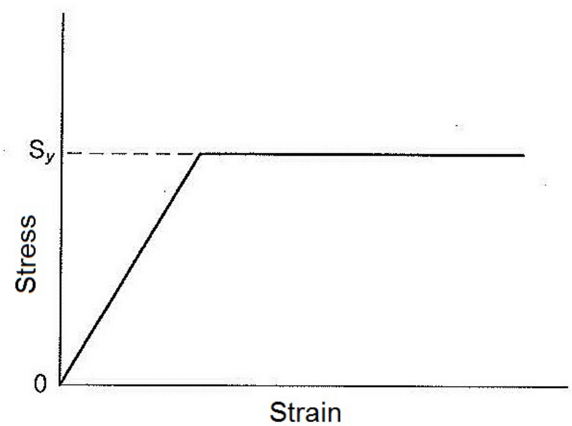

Fig. 4.1 Elastic perfectly plastic stress-strain relationship used as the basis for limit design theory

Limit load analysis is based on the theory of limit analysis that defines a lower bound to the limit load of a component as the solution of a numerical model with the following properties:

1. The material model is elastic-perfectly plastic at a specified yield strength, S_y.
2. The strain-displacement relations are those of small displacement theory.
3. Equilibrium is satisfied in the undeformed configuration.

In a solid bar with a rectangular cross section made from elastic-perfectly plastic material, limit design theory predicts 'collapse' of the bar under either of the following loading conditions.

(a) Collapse occurs whenever the bar is subject to an axial tensile stress, P_m, equal to the yield strength, S_y. When expressed as an equation, collapse occurs when $P_m = S_y$.

(b) Collapse occurs whenever the bar is subject to a bending stress, P_b, equal to the yield strength, S_y, times a shape factor equal to 1.5. When expressed as an equation, collapse occurs when $P_b = 1.5S_y$.

A shape factor of 1.5 corresponds to a beam with a rectangular cross section that is loaded in bending so that the ratio between the moment associated with a fully plastic cross section and the moment associated with first yielding of the outer fiber of the beam equals 1.5. Thus, a beam with a rectangular cross section can resist 50% additional moment before a fully plastic hinge forms compared to a fully elastic beam in which the bending stress at the outer edge of the beam equals the yield strength, S_y.

When the primary stress in a bar with a rectangular cross section consists of a combination of bending stress and axial stress, the limit load depends on the ratio between the axial and bending stresses. As previously discussed for loading condition (b) above, when the average axial tensile stress, P_m, is zero, the limit load occurs when the bending stress, P_b, equals $1.5S_y$. However, as axial stress, P_m, increases, the limit load decreases because there is less material available to resist bending.

Equation {4.4} shows the relationship between limit load bending stress, P_b, and axial stress, P_m.

$$P_b/S_y = 1.5\left[1 - \left(P_m/S_y\right)^2\right] \qquad \text{for } 0 \le P_m/S_y \le 1.0 \qquad \{4.4\}$$

This equation defines the plastic collapse stress limit envelope for an axial stress to yield strength ratio, P_m/S_y, between 0 and 1. It was derived by summing moments about the neutral axis of a solid bar with a rectangular cross section and an elastic-plastic stress-strain curve subjected to combined axial and bending stresses.

Figure 4.2 of this report shows how the plastic collapse stress limit envelope at the outer fiber of an elastic perfectly plastic rectangular bar varies as the average axial stress across the bar increases. Note that the bending stress, P_b, and axial stress, P_m, are normalized by the yield strength, S_y, and the ratio of the axial stress to the yield strength, P_m/S_y, is limited to a range of 0 to 1. Maximum allowable design stresses specified in the ASME BPVC are well within this plastic collapse stress limit envelope as discussed in Sect. 4.8 of this report.

The maximum allowable design stress values published in the 2007 and 2021 editions of Section II, Part D of the ASME BPVC are based on the following stress limits as discussed in Sect. 4.4 of this report.

$$P_m \le S_y \quad \text{Stress limit} \qquad \{4.5\}$$

$$P_m + P_b \le 1.5S_y \quad \text{Stress limit} \qquad \{4.6\}$$

Adequate safety against plastic collapse for pressure vessels constructed in accordance with rules specified in the 2007 and 2021 editions of Section VIII, Divisions 1 and 2 is achieved by limiting design stresses to 2/3 of these stress limits as stated in Equations {4.7} and {4.8}.

$$P_m \le 0.67S_y \quad \text{Design stress limit} \qquad \{4.7\}$$

$$P_m + P_b \le 1.0S_y \quad \text{Design stress limit} \qquad \{4.8\}$$

In comparison, adequate safety against plastic collapse for boilers constructed in accordance with rules specified in the 2007 and 2021 editions of Section I is achieved by limiting the design membrane stress, P_m, to $2/3S_y$ to be consistent with the maximum stress theory. For boiler components in which bending produces the maximum stress, the design bending stress, P_b, is similarly limited to $2/3S_y$.

Figure 4.3 of this report shows the relationship between design stress limits and the plastic collapse stress limit specified in Section I of the ASME BPVC. The difference in stress values represents a design margin against plastic collapse. Although the difference between design stress limits and the plastic collapse stress limit is not constant, it is important to note that the design margin equals or exceeds 1.5 for all stress combinations.

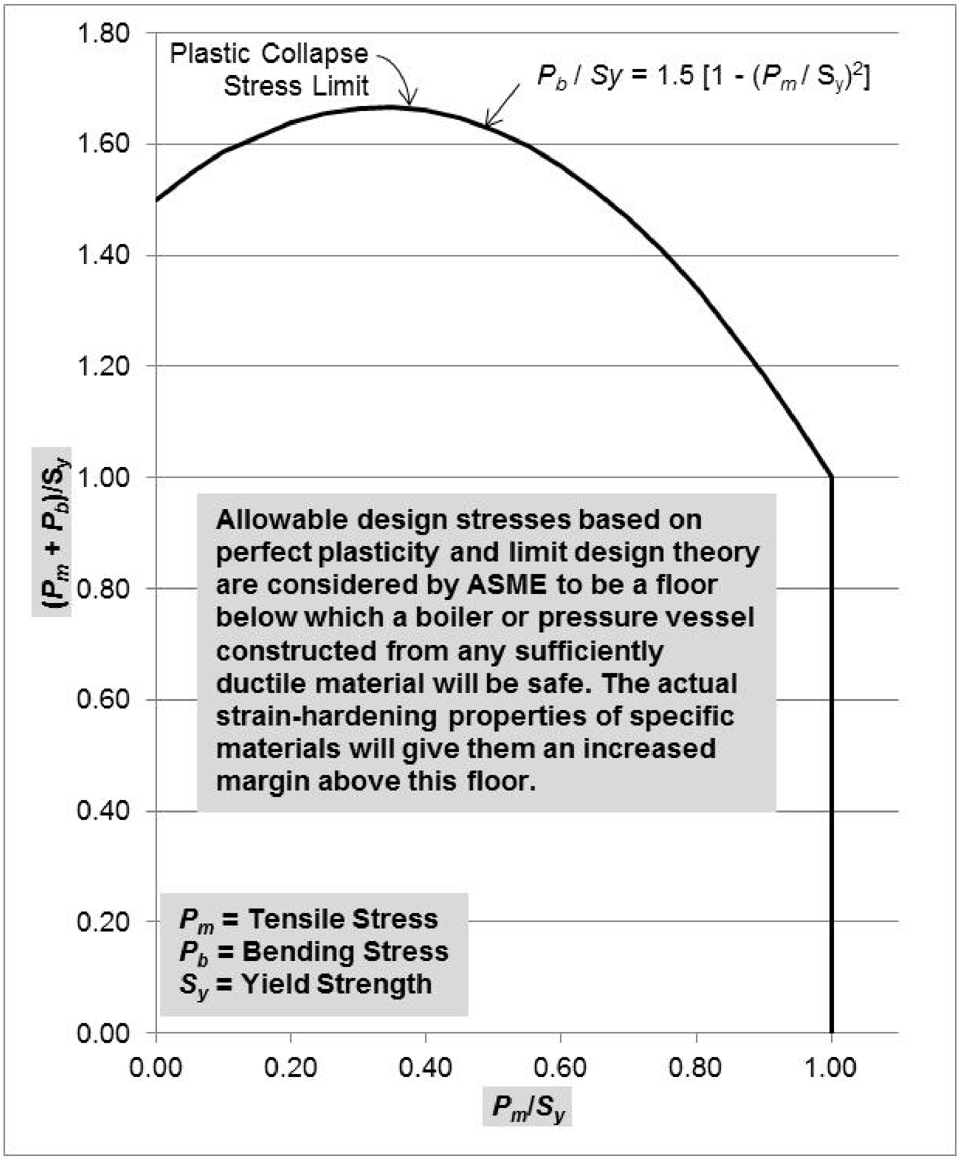

Fig. 4.2 Plastic collapse stress limit used as the basis for establishing maximum allowable design stresses specified in the ASME BPVC

Figure 4.4 of this report shows the corresponding relationships between the design stress limits expressed by Equations {4.7} and {4.8} and the plastic collapse stress limit specified in Section VIII, Divisions 1 and 2 of the ASME BPVC. The difference in stress values represents a design margin against plastic collapse. Although the difference between design stress limits and the plastic collapse stress limit is not constant, it is important to note that the design margin equals or exceeds 1.5 for all stress combinations.

4.7 STRESS RANGE FOR REPETITIVELY APPLIED LOADS

Rules in Paragraph 5.5.6*(d)* in the 2007 edition and Paragraph 4.1.6.3 in the 2021 edition of Section VIII, Division 2 in the ASME BPVC limits the allowable primary plus secondary stress range, S_{PS}, to 3.0 times the maximum allowable stress value in tension or 2.0 times the minimum specified yield strength, S_y, of the material as follows:

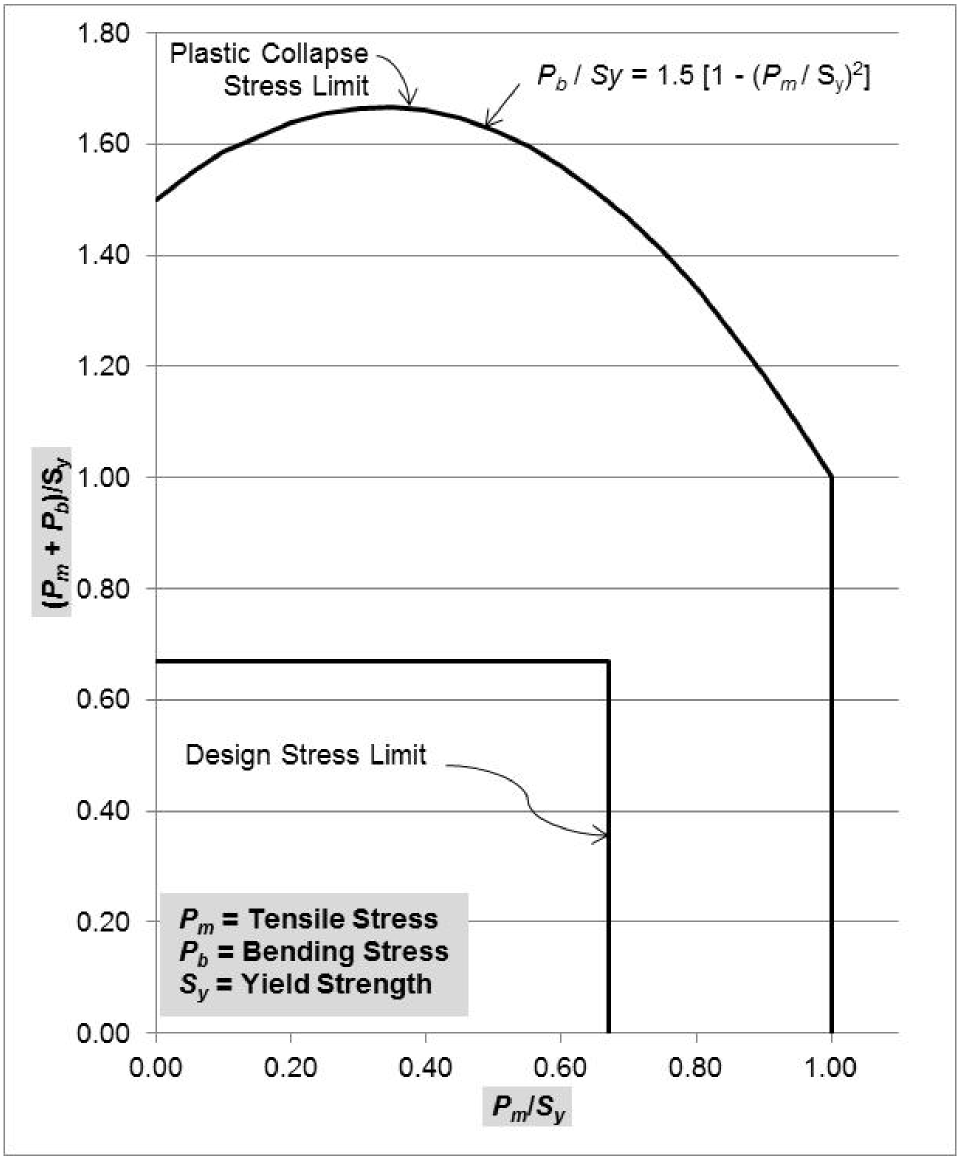

Fig. 4.3 Comparison of design stress limit specified in the 2007 and 2021 editions of Section I in the ASME BPVC to plastic collapse stress limit

$$S_{PS} = \max[3S, 2S_y] \qquad \{4.1.6\}$$

However, S_{PS}, shall be limited to $3S$ if either:

1. the room temperature ratio of the minimum specified yield strength from Annex 3-D to the ultimate tensile strength from Annex 3-D exceeds 0.70; or,
2. the allowable stress from Annex 3-A is governed by time-dependent properties.

This requirement ensures the material has strain-hardening properties sufficient to prevent material failure if the primary stress exceeds the yield strength of the material through the entire thickness. The cyclic stress–strain curve of a material (i.e., strain amplitude versus stress amplitude) may be represented by an equation provided in Annex 3-D – Strength Parameters in the 2007 and 2021 editions of Section VIII, Division 2 in the ASME BPVC. The material constants for this equation, which are tabulated in Annex 3-D, are temperature and material dependent.

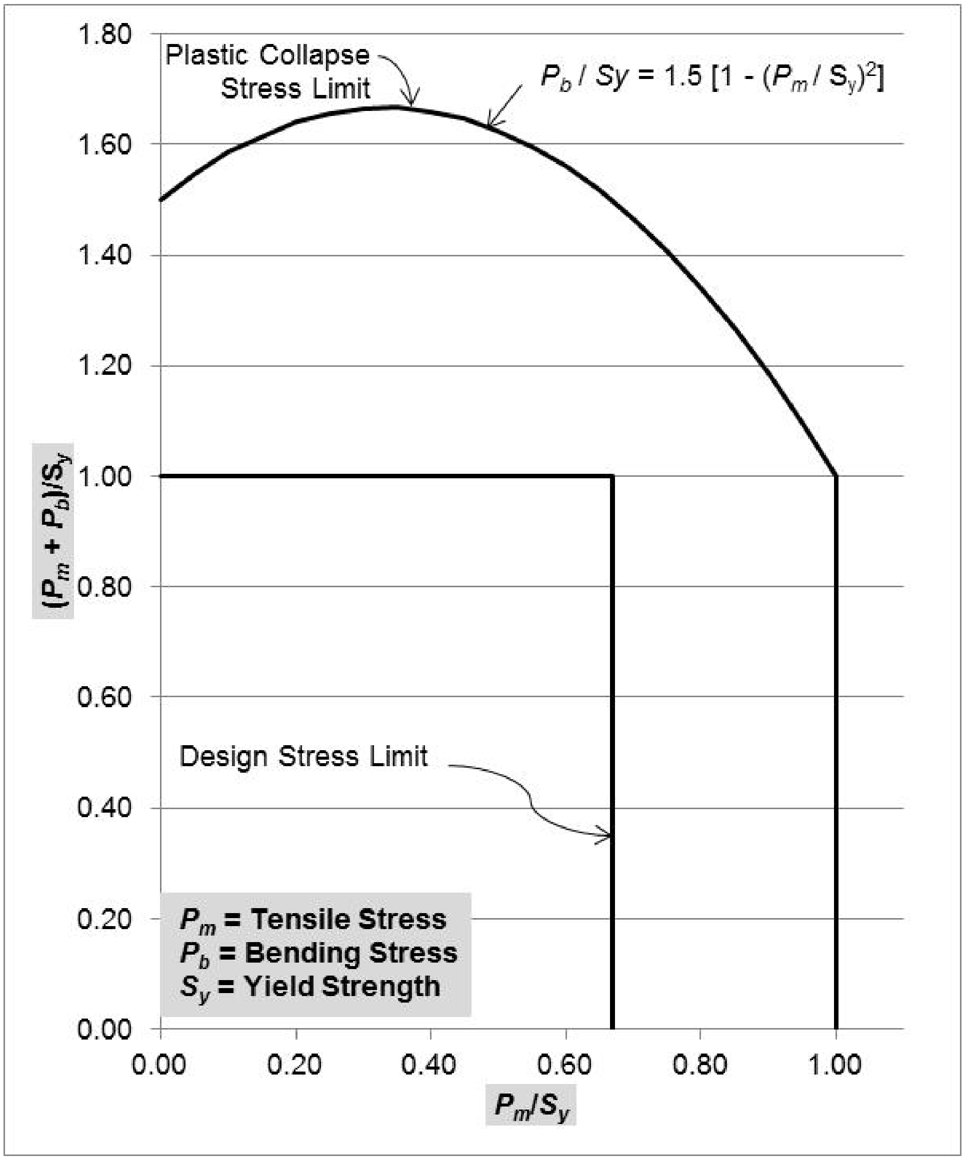

Fig. 4.4 Comparison of design stress limit specified in the 2007 and 2021 editions of Section VIII, Divisions 1 and 2 in the ASME BPVC to plastic collapse stress limit

A calculated elastic stress range equal to twice the yield strength, S_y, is significant because it determines the borderline between loads which, when repetitively applied, allow the component to 'shakedown' to elastic action and loads which produce plastic action each time they are applied. Shakedown of a component occurs if, after a few cycles of load application, ratcheting ceases. The subsequent structural response is elastic, or elastic-plastic, and progressive incremental inelastic deformation is absent. Elastic shakedown is the case in which the subsequent response is elastic. The following definition of shakedown is provided in Part 5, Paragraph 5.12 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC.

Caused by cyclic loads or cyclic temperature distributions which produce plastic deformations in some regions of the component when the loading or temperature distribution is applied, but upon removal of the loading or temperature distribution, only elastic primary and secondary stresses *are developed in the component, except in small areas associated with local stress (strain) concentrations. These small areas shall exhibit a stable hysteresis loop, with no indication of progressive deformation. Further loading and unloading, or applications and removals of the temperature distribution shall produce only elastic primary and secondary stresses.*

To illustrate this 'shakedown' phenomenon, consider the condition where the outer fiber of a beam which is strained in tension to a strain value ε_1, somewhat beyond the yield strain, ε_y, as shown in Fig. 4.5(a) of this report by the path *OAB*. The calculated elastic stress is $S = S_1 = E\varepsilon_1$. In this illustration of a secondary stress, it is assumed that the nature of the loading is such as to cycle the strain from zero to ε_1 and back to zero, rather than cycling the stress from zero to S_1, and back to zero. When the beam is returned to its original position, the outer fiber has a residual compressive stress of magnitude $S_1 - S_y$. On any subsequent loading, this residual compression must be removed before the stress goes into tension and thus the elastic range has been increased by the quantity $S_1 - S_y$. If $S_1 = 2S_y$, the elastic range becomes $2S_y$, but if $S_1 > 2S_y$, the fiber yields in compression, as shown by *EF* in Fig. 4.5(b) of this report and all subsequent cycles produce plastic strain. Therefore, $2S_y$ is the maximum value of calculated secondary elastic stress which will 'shake down' to purely elastic action.

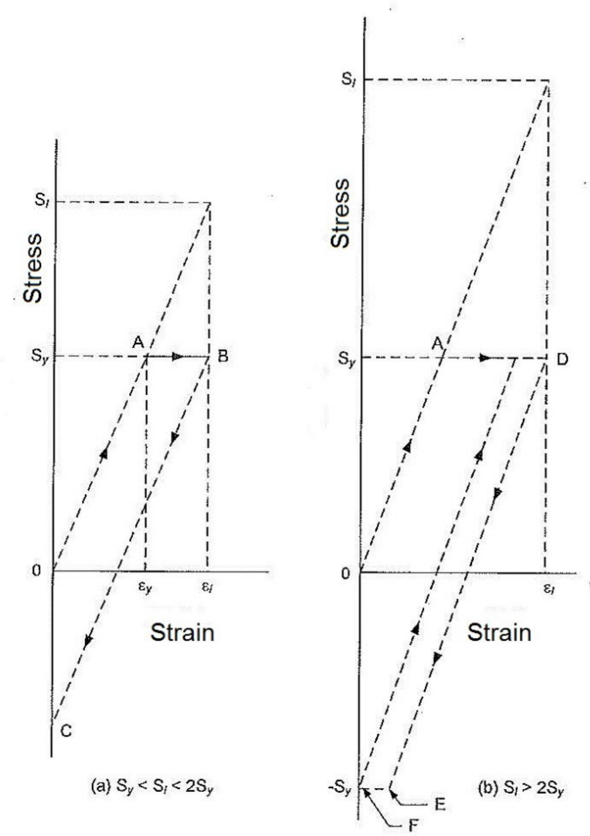

Fig. 4.5 Stress-strain relationship beyond yield for cyclic loading

In addition, Part 5, Paragraph 5.5.7 in the 2007 and 2015 editions of Section VIII, Division 2 of the ASME BPVC states:

To evaluate protection against ratcheting using elastic-plastic analysis, an assessment is performed by application, removal and reapplication of the applied loadings. If protection against ratcheting is satisfied, it may be assumed that progression of the stress-strain hysteresis loop along the strain axis cannot be sustained with cycles and that the hysteresis loop will *stabilize. A separate check for plastic shakedown to alternating plasticity is not required. The following assessment procedure can be used to evaluate protection against ratcheting using elastic-plastic analysis.*

An important point to note from the foregoing discussion of primary and secondary stresses is that $1.5S_y$ is the failure stress for primary bending, whereas for secondary bending $2S_y$ is merely the threshold beyond which some plastic action occurs. Therefore, the allowable design stress for primary bending must be reduced below $1.5S_y$, whereas $2S_y$ is a safe design value for secondary bending because minor plastic action during overloads is tolerable. The same type of analysis shows that $2S_y$ is also a safe design value for secondary membrane tension. As described previously in Sect. 4.3 of this report, local membrane stress produced by mechanical load has the characteristics of a secondary stress but has been arbitrarily placed in the primary category. To avoid excessive distortion, it has been assigned an allowable stress level of S_y, which is 50% higher than the allowable general primary membrane stress of $2/3\,S_y$ but precludes excessive yielding.

Section I and Section VIII, Division 1 of the ASME BPVC do not consider the possibility of fatigue failure. Therefore, Section I and Section VIII, Division 1 of the ASME BPVC do not include rules for the 'shakedown' phenomenon. Text in Paragraph UG-23(*c*) of the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC states:

It is recognized that high localized discontinuity stresses may exist in vessels designed and fabricated in accordance with these rules. Insofar as practical, design rules for details have been written to limit such stresses to a safe level consistent with experience.

4.8 PLASTIC COLLAPSE

Plastic collapse is defined as the onset of gross plastic deformations. Plastic collapse corresponds to the load at which overall structural instability occurs. The collapse load is defined as the maximum load limit for a component made of elastic perfectly plastic material. The collapse load is derived from an elastic-plastic analysis considering both the applied loading and deformation characteristics of the component where the deformations of these components increase without bound at the collapse load.

4.8.1 Plastic Collapse Requirements in Section I and Section VIII, Division 1

Section I and Section VIII, Division 1 of the ASME BPVC do not require a detailed stress analysis to evaluate protection against plastic collapse but merely set the wall thickness necessary to keep the basic hoop stress below the tabulated allowable stress. As discussed in Sect. 4.4 of this report, the primary stress for boilers and pressure vessels constructed in accordance with rules specified in the 2007 and 2021 editions of Section I and Section VIII, Division 1 of the ASME BPVC is limited to two-thirds of the yield strength, $2/3\,S_y$, or less. The primary stress is the maximum principal stress which may be either a membrane stress or a bending stress, whichever is greater. Rules specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC also ensure that the primary membrane stress plus the primary bending stress, $P_m + P_b$, does not exceed S_y. Based on the principles of limit design theory discussed in Sect. 4.6 of this report, these rules provide a minimum design margin against plastic collapse equal to or greater than 1.5 for all primary membrane and bending stress combinations.

4.8.2 Plastic Collapse Requirements in Section VIII, Division 2

As discussed in Sect. 4.4.2 and 4.4.5 of this report, rules specified in Part 4, Paragraph 4.1.6.1 in the 2007 and 2021 editions of Section VIII, Division 2 ensure that the maximum allowable primary membrane stress, P_m, does not exceed $2/3S_y$ and that the maximum allowable primary membrane stress plus primary bending stress, $P_m + P_b$, does not exceed S_y. These maximum allowable stress limits are consistent with the plastic collapse stress limits discussed in Sect. 4.6 of this report.

Three alternative analysis methods are provided in Part 5, Paragraph 5.2 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC for evaluating protection against plastic collapse. Brief descriptions of these analysis methods follow.

1. Elastic Stress Analysis Method – Stresses are computed using an elastic analysis, classified into categories, and limited to allowable values that have been conservatively established such that a plastic collapse will not occur.
2. Limit-Load Method – A calculation is performed to determine a lower bound to the limit load of a component. The allowable load on the component is established by applying design factors to the limit load such that the onset of gross plastic deformations (plastic collapse) will not occur.
3. Elastic-Plastic Stress Analysis Method – A collapse load is derived from an elastic-plastic analysis considering both the applied loading and deformation characteristics of the component. The allowable load on the component is established by applying design factors to the plastic collapse load.

For components with complex geometries and loadings, the categorization of stresses requires significant knowledge and judgment by the analyst. This is especially true for three-dimensional stress fields [6].

4.9 DESIGN-BY-RULE

The design approach used in the 2007 and 2021 editions of Section I; Section VIII, Division 1; and Section VIII, Division 2, Part 4 of the ASME BPVC is referred to as design-by-rule. The design-by-rule approach has evolved from theory, experiment, and past successful experience.

Design-by-rule is not based on a detailed stress analysis. Instead, design-by-rule generally involves calculation of average membrane stress across the thickness of the walls of the boiler or pressure vessel. Application of design-by-rule involves determination of loads, selection of a design equation, and the selection of an appropriate allowable design stress for the material [6].

4.9.1 Design-by-Rule Requirements in Section I

Rules specified in the 2007 and 2021 editions of Section I of the ASME BPVC do not:

- require calculation of thermal stresses and do not provide allowable values for them.
- require the detailed calculation and classification of all stresses and the application of different stress limits to different classes of stress.
- consider the possibility of fatigue failure [6].

Instead, rules in the 2007 and 2021 editions of Section I of the ASME BPVC provide allowable stress limits for ensuring that the maximum allowable primary membrane stress, P_m, does not exceed $2/3S_y$ and equations for minimum wall thickness based on the maximum stress theory as discussed in Sects. 4.4.1 and 4.5.1 of this report.

As previously discussed in Sect. 4.5.1 of this report, equations specified in the 2007 and 2021 editions of Section I of the ASME BPVC for determining wall thickness are, by implication, consistent with the maximum stress theory. For thin-walled cylindrical pressure components at locations that are remote from any discontinuities, the hoop stress is twice the axial stress and the radial stress on the inside is compressive and equal to the internal pressure, p.

Rules for openings and compensation are specified in Paragraphs PG-32 through PG-39 in the 2007 and 2021 editions of Section I of the ASME BPVC. These rules are based on the area replacement concept in which the metal cut out by an opening must be replaced by reinforcement within a prescribed zone around the opening. A detailed discussion of this concept is presented in WRC Bulletin 335 [11]. The reference note for Paragraphs PG-32 through PG- 39 in the 2007 and 2021 editions of Section I of the ASME BPVC states:

> *The rules governing openings as given in this Code are based on the stress intensification created by the existence of a hole in an otherwise symmetrical section. They are based on experience with vessels designed with safety factors of 4 and 5 applied to the specified minimum tensile strength of the shell material. External loadings such as those due to thermal expansion or to unsupported weight of connecting piping have not been evaluated. These factors should be given attention in unusual designs or under conditions of cyclic loading.*

Rules specified in Paragraph PG-32 – Openings in Shells, Headers, and Heads in the 2007 edition of Section I of the ASME BPVC was revised in the 2021 edition to state: Larger openings should be given special attention and may be provided with compensation in any suitable manner that complies with the intent of the Code rules. It is recommended that the compensation provided be distributed close to the opening. (A provision of about two-thirds of the required compensation within a distance of three-fourths times the limit established in PG-36.2 on each side of the opening as measured from the center of the opening is suggested.) Special consideration should be given to the fabrication details used and the inspection employed on critical openings; compensation often may be advantageously obtained by use of a thicker shell plate for a vessel course or inserted locally around the opening; welds may be ground to concave contour and the inside corners of the opening rounded to a generous radius to reduce stress concentrations. In extreme cases of large openings approaching full vessel diameter, openings of unusual shape, etc., the requirements of PG-16.1 may be advisable.

4.9.2 Design-by-Rule Requirements in Section VIII, Division 1

Paragraph UG-23*(c)* in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC provides rationale for design-by-rule requirements stating that:

> *It is recognized that high localized discontinuity stresses may exist in vessels designed and fabricated in accordance with these rules. Insofar as practical, design rules for details have been written to limit such stresses to a safe level, consistent with experience.*

Rules specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC do not:

- require calculation of thermal stresses and do not provide allowable values for them.
- require the detailed calculation and classification of all stresses and the application of different stress limits to different classes of stress.
- consider the possibility of fatigue failure [6].

Instead, rules in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC provide allowable stress limits for ensuring that the maximum allowable primary membrane stress, P_m, does not exceed $2/3S_{yy}$, the maximum primary membrane stress plus primary bending stress, $P_m + P_b$, does not exceed S_y and equations for minimum wall thickness based on the maximum stress theory as discussed in Sect. 4.4.1 of this report.

As previously discussed in Sect. 4.5.1 of this report, equations specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC for determining wall thickness are, by implication, consistent with the maximum stress theory. For thin-walled cylindrical pressure vessels at locations that are remote from any discontinuities, the hoop stress is twice the axial stress and the radial stress on the inside is compressive and equal to the internal pressure.

Rules for openings and compensation are specified in Paragraphs UG-36 through UG-39 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. These rules are based on the area replacement concept in which the metal cut out by an opening must be replaced by reinforcement within a prescribed zone around the opening. A detailed discussion of this concept is presented in WRC Bulletin 335 [11]. The reference note for Paragraphs UG-36 through UG-39 in the 2007 edition of Section VIII, Division 1 of the ASME BPVC states:

> *The rules governing openings as given in this Division are based on the stress intensification created by the existence of a hole in an otherwise symmetrical section. External loadings such as those due to the thermal expansion or unsupported weight of connecting piping have not been evaluated. These factors should be given attention in unusual designs or under conditions of cyclic loading.*

Supplementary design formulas are specified in Mandatory Appendix 1 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC for:

- Rules for reinforcement of cones and conical reducers under external pressure.
- Alternative rules for reinforcement of openings under internal pressure.
- Alternative method for design of reinforcement for openings in cylindrical and conical shells under internal pressure.

4.9.3 Design-by-Rule Requirements in Section VIII, Division 2

Rules for the design-by-rule methods are specified in Part 4 – Design by Rule Requirements in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. Detailed design procedures are provided for commonly used pressure vessel shapes under pressure loading and, within specified limits, rules, or guidance for treatment of other loadings. Individual paragraphs in Part 4 in the 2021 edition of Section VIII, Division 2 cover the following subjects.

4.1 – General Requirements

4.2 – Design Rules for Welded Joints

4.3 – Design Rules for Shells Under Internal Pressure

4.4 – Design of Shells Under External Pressure and Allowable Compressive Stresses

4.5 – Design Rules for Openings in Shells and Heads

4.6 – Design Rules for Flat Heads

4.7 – Design Rules for Spherically Dished Bolted Covers

4.8 – Design Rules for Quick-Actuating (Quick Opening) Closures

4.9 – Design Rules for Braced and Stayed Surfaces

4.10 – Design Rules for Ligaments

4.11 – Design Rules for Jacketed Vessels

4.12 – Design Rules for Noncircular Vessels

4.13 – Design Rules for Layered Vessels

4.14 – Evaluation of Vessels Outside of Tolerance

4.15 – Design Rules for Supports and Attachments

4.16 – Design Rules for Flanged Joints

4.17 – Design Rules for Clamped Connections

4.18 – Design Rules for Shell and Tube Heat Exchangers

4.19 – Design Rules for Bellows Expansion Joints

4.20 – Design Rules for Flanged-and-Flued or Flanged-Only Expansion Joints

Although Part 4 is comprehensive, it does not provide rules to cover all loadings, geometries, and details. When design rules are not provided for a pressure vessel or pressure vessel part, a stress analysis in accordance with Part 5 – Design by Analysis Requirements must be performed considering all of the loadings specified in the User's Design Specification. The design procedures in Part 4 may be used if the allowable stress at the design temperature is governed by time-independent or time-dependent properties unless otherwise noted in a specific design procedure. When the pressure vessel is operating at a temperature where the allowable stress is governed by time-dependent properties, the effects of joint alignment and weld peaking in shells and heads must be considered.

As previously discussed in Sect. 4.5.2 of this report, beginning with the 2007 edition of Section VIII, Division 2 of the ASME BPVC, the specified design-by-rule equations in Part 4 are based on a limit analysis using the maximum shear stress theory.

Design rules for openings in shells and heads are specified in Part 4, Paragraph 4.5 in the 2007 and 2021 editions of Section VIII, Division 2. The rules in Paragraph 4.5 are applicable for the design of nozzles in shells and heads subjected to internal pressure, external pressure, and external forces and moments from supplemental loads as defined in Paragraph 4.1. Design procedures for the following types of nozzles and other design rules for nozzles and opening are specified in Paragraphs 4.5.2 through 4.5.17:

- Dimensions and Shape of Nozzles
- Method of Nozzle Attachment
- Nozzle Neck Minimum Thickness Requirements
- Radial Nozzle in a Cylindrical Shell
- Hillside Nozzle in a Cylindrical Shell
- Nozzle in a Cylindrical Shell Oriented at an Angle from the Longitudinal Axis
- Radial Nozzle in a Conical Shell
- Nozzle in a Conical Shell
- Radial Nozzle in a Spherical Shell or Formed Head
- Hillside or Perpendicular Nozzle in a Formed Head
- Circular Nozzles in a Flat Head
- Spacing Requirements for Nozzles
- Strength of Nozzle Attachment Welds
- Local Stresses in Nozzles in Shells and Formed Heads from External Loads
- Inspection Openings
- Reinforcement of Openings Subject to Compressive Stress

The traditional ASME area replacement approach to designing openings in pressure vessels provides safe designs because yield strength governs the design of openings for most materials. However, the area replacement approach results in a conservative local primary stress and a bias towards over reinforcement for certain nozzle geometries. From a safety viewpoint, excessive reinforcement can be detrimental to fatigue life. To benefit from the increase in allowable stresses permitted in the 2007 and 2021 editions of Section II in the ASME BPVC, rules in Part 4, Paragraph 4.5 explicitly limit local primary stresses at the opening. The objectives of the rules in Part 4, Paragraph 4.5 are to:

1. provide a more accurate design.
2. consider a wider range of geometries.
3. provide direction for calculation of local primary membrane equivalent stresses and attachment weld stresses.

These rules use a modified pressure area method to determine the magnitude of the discontinuity force resisted locally. They also explicitly consider thick shells. Openings in flat heads are provided with a separate set or rules that are based on beam on elastic foundation principles.

Configurations, including dimensions and shape, or loading conditions that do not satisfy the rules of Paragraph 4.5 may be designed in accordance with Part 5.

4.10 DESIGN-BY-ANALYSIS

Rules for the design-by-analysis methods are specified in Part 5 – Design by Analysis Requirements in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. Detailed design procedures utilizing the results from a stress analysis are provided to evaluate components for plastic collapse, local failure, buckling, and cyclic loading. Supplemental requirements are provided for the analysis of bolts, perforated plates, and layered vessels. Procedures are also provided for design using the results from an experimental stress analysis, and for fracture mechanics evaluations. The design-by-analysis methods is used to design Class 2 pressure vessels that are consistent with allowable stress values in Table 5A or Table 5B in Section II, Part D of the ASME BPVC as discussed in Sect. 4.4.5 of this report.

The design-by-analysis requirements are organized based on protection against the failure modes listed below. The component is evaluated for each applicable failure mode. If multiple assessment procedures are provided for a failure mode, only one of these procedures must be satisfied to qualify the design of a component.

- Paragraph 5.2 – Protection Against Plastic Collapse – these requirements apply to all components where the thickness and configuration of the component is established using design-by-analysis rules.
- Paragraph 5.3 – Protection Against Local Failure – these requirements apply to all components where the thickness and configuration of the component is established using design-by-analysis rules. It is not necessary to evaluate the local strain limit criterion if the component design is in accordance with the component wall thickness and weld details of Part 4.
- Paragraph 5.4 – Protection Against Collapse from Buckling – these requirements apply to all components where the thickness and configuration of the component is established using design-by-analysis rules and the applied loads result in a compressive stress field.
- Paragraph 5.5 – Protection Against Failure from Cyclic Loading – these requirements apply to all components where the thickness and configuration of the component is established using design-by-analysis rules and the applied loads are cyclic. In addition, these requirements can also be used to qualify a component for cyclic loading where the thickness and size of the component are established using the design-by-rule requirements of Part 4.

The design-by-analysis procedures in Part 5 may only be used if the allowable stress at the design temperature is governed by time-independent properties unless otherwise noted in a specific design procedure. Supplemental requirements for stress classification in nozzle necks, bolts, perforated plates, and layered vessels are specified in Part 5, Paragraphs 5.6 through 5.9, respectively.

Requirements for experimental stress analysis are provided in Part 5, Paragraphs 5.10. This paragraph references rules in Annex 5-F for experimental stress and fatigue analysis. Part 5, Paragraphs 5.11 provides requirements for fracture mechanics evaluations performed to determine the MDMT.

Beginning with the 2007 edition of Section VIII, Division 2 of the ASME BPVC, the specified design-by-analysis equations in Part 5 are based on a limit analysis using the distortion energy theory (also known as the octahedral shear theory and the von Mises criterion) given by Equation {4.3} in Sect. 4.5.3 of this report.

4.11 COMPARISON OF KEY DIFFERENCES IN ASME BPVC DESIGN RULES

A comparison of key differences and similarities in design criteria between the 2007 and 2021 editions of the ASME BPVC is presented in Table 4.14 of this report.

Table 4.14 Design criteria comparison

Design Criteria	Comparison
Strength Theory – Section I	2007 – rules are based on the maximum stress theory. 2021 – rules are based on the maximum stress theory
Strength Theory – Section VIII, Division 1	2007 – rules are based on the maximum stress theory. 2021 – rules are based on the maximum stress theory
Strength Theory – Section VIII, Division 2, Part 4 – Design by Rule	2007 – rules are based on the maximum shear stress theory (also known as the Tresca yield criterion). 2021 – rules are based on the maximum shear stress theory (also known as the Tresca yield criterion).
Strength Theory – Section VIII, Division 2, Part 5 – Design by Analysis	2007 – rules are based on the distortion energy theory (also known as the octahedral shear theory and the Mises criterion). 2021 – rules are based on the distortion energy theory (also known as the octahedral shear theory and the Mises criterion).
Maximum allowable stress – Section I	2007 – maximum allowable stress limit lesser of $S_t/3.5$ or $2/3S_y$ 2021 – maximum allowable stress limit lesser of $S_t/3.5$ or $2/3S_y$
Maximum allowable stress – Section VIII, Division 1	2007 – maximum allowable stress limit lesser of $S_t/3.5$ or $2/3S_y$ 2021 – maximum allowable stress limit lesser of $S_t/3.5$ or $2/3S_y$
Maximum allowable stress – Section VIII, Division 2	2007 – maximum allowable stress limit lesser of $S_t/2.4$ or $2/3S_y$ 2021 – maximum allowable stress limit lesser of $S_t/3.0$ or $2/3S_y$ for Class 1 2021 – maximum allowable stress limit lesser of $S_t/2.4$ or $2/3S_y$ for Class 2
Stress calculation and classification – Section I	2007 – equations are specified for minimum allowable wall thickness, therefore, detailed calculation and classification of all stresses and the application of different stress limits to different classes of stress are not required. 2021 – equations are specified for minimum allowable wall thickness, therefore, detailed calculation and classification of all stresses and the application of different stress limits to different classes of stress are not required.

Design Criteria	Comparison
Stress calculation and classification – Section VIII, Division 1	2007 – equations are specified for minimum allowable wall thickness, therefore, detailed calculation and classification of all stresses and the application of different stress limits to different classes of stress are not required. 2021 – equations are specified for minimum allowable wall thickness, therefore, detailed calculation and classification of all stresses and the application of different stress limits to different classes of stress are not required.
Stress calculation and classification – Section VIII, Division 2	2007 –detailed calculation and classification of all stresses and the application of different stress limits to different classes of stress are required. 2021 –detailed calculation and classification of all stresses and the application of different stress limits to different classes of stress are required.
Calculation of thermal stress – Section I	2007 – thermal stress calculations are not required, and allowable thermal stress values are not specified. 2021 – thermal stress calculations are not required, and allowable thermal stress values are not specified.
Calculation of thermal stress – Section VII, Division 1	2007 – thermal stress calculations are not required, and allowable thermal stress values are not specified. 2021 – thermal stress calculations are not required, and allowable thermal stress values are not specified.
Calculation of thermal stress – Section VII, Division 2	2007 – thermal stress calculations are required, and allowable thermal stress values are specified. 2021 – thermal stress calculations are required, and allowable thermal stress values are specified.
Excessive elastic deformation and elastic instability – Section I	2007 – charts and tables are provided for determining shell thickness of components under external pressure 2021 – charts and tables are provided for determining shell thickness of components under external pressure
Excessive elastic deformation and elastic instability – Section VIII, Division 1	2007 – charts and tables are provided for determining shell thickness of components under external pressure 2021 – charts and tables are provided for determining shell thickness of components under external pressure
Excessive elastic deformation and elastic instability – Section VIII, Division 2	2007 – rules are provided for protection against collapse from buckling including three alternative types of buckling analyses. 2021 – rules are provided for protection against collapse from buckling including three alternative types of buckling analyses.
Excessive plastic deformation – Section I	2007 – rules for protection against plastic collapse are not specifically provided, but the maximum allowable stress is limited to two-thirds of the yield strength, $2/3S_y$, or less. 2021 – rules for protection against plastic collapse are not specifically provided, but the maximum allowable stress is limited to two-thirds of the yield strength, $2/3S_y$, or less.

Design Criteria	Comparison
Excessive plastic deformation – Section VIII, Division 1	2007 – rules for protection against plastic collapse are not specifically provided, but the maximum allowable stress is limited to two-thirds of the yield strength, $2/3S_y$, or less. In addition, rules ensure that the primary membrane stress plus the primary bending stress, $P_m + P_b$, does not exceed S_y. 2021 – rules for protection against plastic collapse are not specifically provided, but the maximum allowable stress is limited to two-thirds of the yield strength, $2/3S_y$, or less. In addition, rules ensure that the primary membrane stress plus the primary bending stress, $P_m + P_b$, does not exceed S_y.
Excessive plastic deformation – Section VIII, Division 2	2007 – three alternative analysis methods are provided in Part 5, Paragraph 5.2 for evaluating protection against plastic collapse. (*a*) Elastic Stress Analysis Method (*b*) Limit-Load Method (*c*) Elastic-Plastic Stress Analysis Method 2021 – three alternative analysis methods are provided in Part 5, Paragraph 5.2 for evaluating protection against plastic collapse. (*a*) Elastic Stress Analysis Method (*b*) Limit-Load Method (*c*) Elastic-Plastic Stress Analysis Method
Brittle fracture – Section I	2007 – no fracture toughness requirements are provided. 2021 – no fracture toughness requirements are provided.
Brittle fracture – Section VIII, Division 1	2007 – fracture toughness requirements vary depending on the minimum specified yield strength, material type, and material thickness. 2021 – fracture toughness requirements vary depending on the minimum specified yield strength, material type, and material thickness
Brittle fracture – Section VIII, Division 2 (See Tables 4.1, 4.2, and 4.3 of this report and Tables 3.6 in the 2007 and 2021 editions of Section VIII, Division 2)	2007 – fracture toughness requirements are provided for five specific material groups. Minimum Charpy V-notch impact energy and lateral expansion requirements vary over a range from 20 to 61 ft-lb and 0.015 to 0.025 in. depending on material type, thickness, and yield strength. 2021 – fracture toughness requirements are provided for five specific material groups. Minimum Charpy V-notch impact energy and lateral expansion requirements vary over a range from 20 to 61 ft-lb and 0.020 to 0.035 in. depending on material type, thickness, and yield strength.
Fatigue – Section I	2007 – rules for prevention of fatigue failure are not specified. 2021 – rules for prevention of fatigue failure are not specified.
Fatigue – Section VIII, Division 1	2007 – rules for prevention of fatigue failure are not specified. 2021 – rules for prevention of fatigue failure are not specified.
Fatigue – Section VIII, Division 2	2007 – rules for prevention of fatigue failure are specified. 2021 – rules for prevention of fatigue failure are specified.
Openings and reinforcements – Section I	2007 – rules for openings and reinforcements are based on the area replacement concept in which the metal cut out by an opening must be replaced by reinforcement within a prescribed zone around the opening. 2021 – rules for openings and reinforcements are based on the area replacement concept in which the metal cut out by an opening must be replaced by reinforcement within a prescribed zone around the opening.

Design Criteria	Comparison
Openings and reinforcements – Section VIII, Division 1	2007 – rules for openings and reinforcements are based on the area replacement concept in which the metal cut out by an opening must be replaced by reinforcement within a prescribed zone around the opening and include supplementary design formulas for openings and reinforcements. 2021 – rules for openings and reinforcements are based on the area replacement concept in which the metal cut out by an opening must be replaced by reinforcement within a prescribed zone around the opening and include supplementary design formulas for openings and reinforcements.
Openings and reinforcements – Section VIII, Division 2	2007 – rules for openings and reinforcements are specified including supplementary design formulas for openings and reinforcements. These rules use a modified pressure area method to determine the magnitude of the discontinuity force resisted locally. 2021 – rules for openings and reinforcements are specified including supplementary design formulas for openings and reinforcements. These rules use a modified pressure area method to determine the magnitude of the discontinuity force resisted locally.

5. FABRICATION

The term "fabrication" is not explicitly defined in the ASME BPVC, but it is generally understood to mean all activities a manufacturer uses to process and assemble plates, pipes, tubes, and other material products into a complete boiler or pressure vessel consistent with applicable rules in the ASME BPVC. Fabrication activities often involve a broad range of manufacturing methods and processes such as forming, machining, bolting, welding, brazing, and heat treating. These methods and processes tend to change as construction technology evolves and improves over time.

The ASME BPVC places limitations on certain fabrication activities, specifically those involving welding and brazing practices related to boiler and pressure vessel construction, to holders of a valid Certificate of Authorization. As discussed in Sect. 1.3 of this report, no organization may assume responsibility for Code construction without having first received from the ASME a Certificate of Authorization to use the Certification Mark and Designators. In addition, any Manufacturer holding or applying for a Certificate of Authorization must demonstrate a Quality Control System that meets the requirements of ASME CA-1 [2].

5.1 REQUIREMENTS FOR METHODS OF CONSTRUCTION

Requirements in Part PG – General Requirements for All Methods of Construction in the 2007 and 2021 editions of Section I of the ASME BPVC apply to power boilers and high pressure, high-temperature water boilers and liquid phase thermal fluid heaters and to parts and appurtenances thereto and shall be used in conjunction with the specific requirements in the applicable Parts of this Section that pertain to the methods of construction used.

Changes in construction technology now make it practical to construct pressure vessels from thinner and thinner materials. Consequently, cold forming is now performed more than in the past. Forming is generally allowed by any process that does not unduly impair the mechanical properties of the material. It is left to the manufacturer to use judgement in selecting processes that are appropriate for the material. However, manufacturing operations that involve forming can cause impaired service performance, especially in austenitic materials and for components in the creep range. Heat treatment after forming is sometimes required to restore material properties and minimize the threat of premature failure due to recrystallization during the time of operation [12].

5.1.1 Requirements for Methods of Construction in Section I

Requirements for methods of construction are specified in Paragraphs PG-1 through PG-113 in the 2007 and 2021 editions of Section I of the ASME BPVC.

5.1.1.1 Prefabricated or Preformed Pressure Parts

Rules in Paragraph PG-11 – Prefabricated or Preformed Pressure Parts Furnished Without a Certification Mark in Section I in the 2007 edition of the ASME BPVC were revised in the 2021 edition to clarifies requirements for standard pressure parts without a Certification Mark including:

1. cast, forged, rolled, or die-formed nonstandard pressure parts
2. cast, forged, rolled, or die-formed standard pressure parts, either welded or nonwelded, that comply with an ASME product standard

3. cast, forged, rolled, or die-formed standard pressure parts, either welded or nonwelded, that comply with a standard other than an ASME product standard

5.1.1.2 Additional Rules for Boiler Fabrication

Rules for fabrication of boilers are specified in Paragraphs PG-75 through PG-82 in the 2007 and 2021 editions of Section I of the ASME BPVC. These rules cover general requirements, cutting plates and other stock, plate identification, repairs of defects in materials, tube holes and ends, permissible out-of-roundness of cylindrical shells, tolerances for formed heads, and holes for stays.

Requirements in Paragraph PG-75 – General in Section I in the 2007 edition of the ASME BPVC were expanded in the 2021 edition to state:

> *Unless otherwise required to verify compliance with specific parts of this Section, visual examination shall be performed to verify compliance with applicable requirements for dimensions, joint preparation, and alignment prior to welding or joining, and finished weld conditions.*

At the option of the Manufacturer, visual examination may be performed in accordance with Section V, Article 9 – Visual Examination.

5.1.2 Requirements for Methods of Construction in Section VIII, Division 1

Rules for fabrication of pressure vessels are specified in Paragraphs UG-75 through UG-85 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. These rules cover:

- cutting plates and other stock
- material identification
- repairs of defects in materials
- forming pressure parts
- permissible out-of-roundness of cylindrical, conical, and spherical shells
- tolerances for formed heads
- lugs and fitting attachments
- holes for screw stays
- Charpy impact tests (See Table 4.1 of this report)
- heat treatment

5.1.2.1 Rule for Forming Pressure Parts

Paragraph UG-79 – Forming Pressure Parts in the 2021 edition of Section VIII, Division 1 specifies additional rules that are not specified in the 2007 edition of Section VIII, Division 1 of the ASME BPVC. Paragraph UG-79*(a)* states:

> *Limits are provided on cold working of all carbon and low alloy steels, nonferrous alloys, high alloy steels, and ferritic steels with tensile properties enhanced by heat treatment [see UCS 79(d), UNF-79(a), UHA-44(a), and UHT-79(a)]. Forming strains or extreme fiber elongation shall be determined by the equations in Table UG-79-1.*

Table UG-79-1 – Equations for Calculating Forming Strains specifies forming strain equations for cylinders formed from plate, for double curvature (e.g., heads), and tube and pipe bends. When the calculated forming strains exceed the maximum prescribed allowable strains specified in Paragraphs

UCS-79(*d*), UHA-44(*a*), UNF-79(*a*), and UHT-79(*a*), as applicable, and the design temperatures exceed specified limits, postfabrication heat treatment is required.

5.1.2.2 Rule for Permissible Out-Of-Roundness of Cylindrical, Conical, and Spherical Shells

Rule changes to Paragraph UG-80 – Permissible Out-of-Roundness of Cylindrical, Conical, and Spherical Shells in the 2021 edition of Section VIII, Division 1 of the ASME BPVC involved:

1. deletion of Paragraph UG-80*(b)(10)* and *(b)(11)* in the 2007 edition that applied to pressure vessel that operate under external pressure.
2. addition of Paragraph UG-80*(c)* to the 2021 edition that apply to pressure vessel that operate under internal or external pressure.

Paragraph UG-80*(c)* states that vessels and components fabricated of pipe or tube under internal or external pressure may have permissible variations in diameter (measured outside) in accordance with those permitted under the specification covering its manufacture.

5.1.3 Requirements for Methods of Construction in Section VIII, Division 2

Rules for forming shell sections and heads are specified in Part 6 – Fabrication Requirements, Paragraph 6.1.2 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. These rule cover forming of carbon and low alloy steels, high alloy steel parts, nonferrous material parts, lugs and fitting attachments, and spin-holes. Equations for determining extreme fiber elongation are specified in Table 6.1 – Equations for Calculating Forming Strains. Table 6.2 – Post Fabrication Strain Limits and Required Heat Treatment for High Alloy Materials in the 2007 edition was reorganized into Tables 6.2.A and 6.2.B in the 2021 edition as follows.

Tables 6.2.A Post-Cold-Forming Strain Limits and Heat-Treatment Requirements for P-No. 15E Materials

Tables 6.2.B Post-Fabrication Strain Limits and Required Heat Treatment for High Alloy Materials

Post-fabrication strain limits and required heat treatment for nonferrous materials are specified in Table 6.3 – Post Fabrication Strain Limits and Required Heat Treatment for Nonferrous Materials.

5.2 TOLERANCES

The ASME BPVC does not fully address tolerances and the owner or user is responsible for including fabrication tolerances in the design basis for a boiler or pressure vessel as explained below.

Paragraph PG-16.6 in the 2021 edition of Section I of the ASME BPVC states that the Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters shall be considered nominal, and allowable tolerances or local variances should be considered acceptable when based on engineering judgment and standard practices as determined by the designer. In addition, Paragraph PG-16.7 states that the dimensional symbols used in the design formulas throughout this Code do not include any allowance for corrosion, erosion, and forming, except where noted. Additional thickness should be provided where these allowances are applicable. Paragraphs PG-16.6 and PG-16.7 were not include in the 2007 edition of Section I of the ASME BPVC.

Paragraph U-5 – Tolerances in the 2021 edition of Section VIII, Division 1 of the ASME BPVC states that the Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal, and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practices as determined by the designer. Section VIII, Division 1 in the 2007 edition of the ASME BPVC did not include Paragraph U-5 – Tolerances.

Paragraph 1.5 – Tolerances in the 2021 edition of Section VIII, Division 2 of the ASME BPVC states that the Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal, and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practices as determined by the designer. Section VIII, Division 2 in the 2007 edition of the ASME BPVC did not include Paragraph 1.5 – Tolerances.

5.2.1 Formed Head Tolerances

Tolerance requirements for formed heads are provided in Section I; Section VIII, Division 1; and Section VIII, Division 2 of the ASME BPVC.

5.2.1.1 Tolerance for Formed Heads in Section I

Paragraph PG-81 – Tolerance for Formed Heads in the 2007 and 2021 editions of Section I of the ASME BPVC state that when heads are made to an approximate ellipsoidal shape, the inner surface of such heads must lie outside and not inside of a true ellipse drawn with the major axis equal to the inside diameter of the head and one-half the minor axis equal to the depth of the head. The maximum variation from this true ellipse shall not exceed 0.0125 times the inside diameter of the head.

5.2.1.2 Tolerance for Formed Heads in Section VIII, Division 1

Shape deviation requirements for formed heads specified in Paragraph UG-81 – Tolerance for Formed Heads in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC are the same. These requirements apply to inner surfaces of torispherical, toriconical, hemispherical, and ellipsoidal heads.

5.2.1.3 Tolerance for Formed Heads in Section VIII, Division 2

Paragraph 4.3.2 – Shell Tolerances in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC specifies rules for shells of completed vessels and for formed heads. Paragraph 4.3.2.3 in the 2007 and 2021 editions states that shells that do not meet the tolerance requirements of this paragraph may be evaluated using Paragraph 4.14 – Evaluation of Vessels Outside of Tolerance.

Paragraph 4.4.4.1 – Permissible Out-of-Roundness of Cylindrical and Conical Shells in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC states that a shell of a completed vessel subject to external pressure shall meet the following requirements at any cross section.

(a) The out-of-roundness requirements in 4.3.2.1 shall be satisfied.
(b) The maximum plus or minus deviation from a true circle, e, measured from a segmental circular template having the design inside or outside radius (depending on where the measurements are taken) and a chord length should not exceed the following value.

5.2.2 Alignment Tolerances

Alignment tolerances are generally intended to ensure complete weld penetration on the inside surfaces of adjoining components [8]. As discussed in Sect. 5.2 of this report, when dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters shall be considered nominal, and allowable tolerances or local variances should be considered acceptable when based on engineering judgment and standard practices as determined by the designer.

5.2.2.1 Alignment Tolerances in Section I

Table PW-33 – Alignment Tolerance of Sections to be Butt Welded in Paragraph PW-33 – Alignment Tolerance, Shells and Vessels (Including Pipe or Tube Used as a Shell) in the 2007 and 2021 editions of Section I of the ASME BPVC specifies alignment tolerance for sections to be butt welded. The alignment tolerance provided in Table PW-33 are the same in 2007 and 2021 editions.

5.2.2.2 Alignment Tolerances in Section VIII, Division 1

Paragraph UW-33 – Alignment Tolerance in the 2007 and 2021editions of Section VIII, Division 1 of the ASME BPVC specify rules for alignment tolerances for edges to be butt welded. The maximum allowable offsets in welded joints are specified in Table UW-33. Alignment tolerance values provided in Table UW-33 are the same in 2007 and 2021 editions.

5.2.2.3 Alignment Tolerances in Section VIII, Division 2

Rules for alignment tolerances for edges to be butt welded are specified in Part 6, Paragraph 6.1.6 – Alignment Tolerances for Edges to be Butt Welded in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. Paragraph 6.1.6.3 – Peaking of Welds in Shells and Heads for Internal Pressure was revised in the 2021 edition to state: If the vessel is operating at a temperature where the allowable stress is governed by time-dependent properties, see 4.1.1.3, or if a fatigue analysis is required, see 4.1.1.4, then the peaking height, P_d, at Category A weld joints shall be measured by either an inside or outside template, as appropriate (See Figure 6.1). As an alternative, the peaking angle may be determined using the procedure described in Part 8 of API 579-1/ASME FFS-1 [9]. This rule change applies to vessel that operate at a temperature where the allowable stress is governed by time-dependent properties.

5.3 WELDING AND BRAZING PROCESSES

Welding was first allowed by the ASME BPVC in 1918, four years after the first edition was published. When initially introduced, welding was only allowed when stresses were carried by other members and safety did not depend on the strength of the weld. Section IX of the ASME BPVC, which specifies rules for welding and brazing, was added to the ASME BPVC in 1941. The rules in Section IX have changed significantly since 1941 and now include rules for welding, brazing, and fusing procedures; welders; brazers; and welding, brazing, and fusing operators.

Section IX is a Reference Codes with rules that apply to boilers and pressure vessels constructed in accordance with rules specified in Section I; Section VIII, Division 1; and Section VIII, Division 2 of the ASME BPVC. However, these Construction Codes may impose additional requirements or exceptions to those specified in Section IX. The scope of Section IX is discussed in Section 2.6 of this report.

An important quality aspect of welding and brazing is the need for control of the joining process to produce sound joints and safe construction. The methodology used by ASME to achieve this objective is to permit joining only by qualified welders, brazers, and fusing operators authorized through the performance qualification process using qualified procedures. These qualified procedures are known as procedure specifications. The principal goal of procedure specification and performance qualification is to assure that the properties of the joint are at least the equivalent of the base materials being joined.

In general, once a procedure specification is qualified, it remains a qualified procedure indefinitely. However, the qualification of any new procedure specification must be in accordance with the current edition of the ASME BPVC. Performance qualification must be demonstrated on a consistent basis because a person's qualification expires if the person does not apply the procedure specification within a six-month period. The opportunity also exists to revoke a person's qualifications at any time when there is specific reason to question the person's ability to make joints that meet the procedure specification. These conditions have remained in place since before the 2007 edition of the ASME BPVC was published.

5.3.1 Base Metal Groupings

Base metals permitted for boiler and pressure vessel construction are grouped by material and assigned P-Numbers. For example, carbon manganese or low carbon steel base metals are assigned to P-No. 1. Table QW/QB-422 in the 2007 and 2021 editions of Section IX of the ASME BPVC provides a cross reference between P-Number and ferrous and nonferrous materials. provides a cross reference between P-Number and ferrous and nonferrous materials.

P-Numbers are assigned to base metals for the purpose of reducing the number of welding and brazing procedure qualifications required. P-Numbers are alphanumeric designations: accordingly, each P-Number must be considered a separate P-Number (e.g., base metals assigned P-No. 5A are considered a separate P-Number from those assigned P-No. 5B or P-No. 5C). Table 5.1 of this report shows the P-Number designations used in the ASME BPVC for various alloy systems.

Table 5.1 P-Number designations used in the ASME BPVC for various alloy systems

Base Metal	Welding	Brazing
Steel and steel alloys	P-No. 1 through P-No. 15F	P-No. 101 through P-No. 103
Aluminum and aluminum-base alloys	P-No. 21 through P-No. 26	P-No. 104 and P-No. 105
Copper and copper-base alloys	P-No. 31 through P-No. 35	P-No. 107 and P-No. 108
Nickel and nickel-base alloys	P-No. 41 through P-No. 49	P-No. 110 through P-No. 112
Titanium and titanium-base alloys	P-No. 51 through P-No. 53	P-No. 115
Zirconium and zirconium-base alloys	P-No. 61 and P-No. 62	P-No. 117

Paragraph PG-5.6 in Section I of the 2021 edition of the ASME BPVC specifies rules that permit use of P-No. 15E, Group 1 materials for boiler construction. Section I in the 2007 edition of the ASME BPVC did not include Paragraph PG-5.6.

5.3.2 Welding and Brazing Methods

Rules for welding and brazing in the 2007 and 2021 editions of Section IX of the ASME BPVC cover the welding and brazing methods identified in Tables 5.2 and 5.3 of this report, respectively.

Table 5.2 Welding methods permitted in Section IX of the ASME BPVC

Welding Method	2007 Edition	2021 Edition
Oxyfuel Gas Welding (OFW)	Yes	Yes
Shielded Metal-Arc Welding (SMAW)	Yes	Yes
Submerged-Arc Welding (SAW)	Yes	Yes

Welding Method	2007 Edition	2021 Edition
Gas Metal-Arc Welding (GMAW and FCAW)	Yes	Yes
Gas Tungsten-Arc Welding (GTAW)	Yes	Yes
Plasma-Arc Welding (PAW)	Yes	Yes
Electroslag Welding (ESW)	Yes	Yes
Electrogas Welding (EGW)	Yes	Yes
Electron Beam Welding (EBW)	Yes	Yes
Stud Welding	Yes	Yes
Inertia and Continuous Drive Friction Welding	Yes	Yes
Resistance Welding	Yes	Yes
Laser Beam Welding (LBW)	Yes	Yes
Low-Power Density Laser Beam Welding (LLBW)	No	Yes
Flash Welding	Yes	Yes
Diffusion Welding (DFW)	No	Yes
Friction Stir Welding (FSW)	No	Yes

Table 5.3 Brazing methods permitted in Section IX of the ASME BPVC

Brazing Method	2007 Edition	2021 Edition
Torch Brazing (TB)	Yes	Yes
Furnace Brazing (FB)	Yes	Yes
Induction Brazing (IB)	Yes	Yes
Resistance Brazing (RB)	Yes	Yes
Dip Brazing — Salt or Flux Bath (DB)	Yes	Yes
Dip Brazing — Molten Metal Bath (DB)	Yes	Yes

5.3.3 Rules in Section IX for Procedure Specification

General requirements in Section IX, Paragraph QG-101 – Procedure Specification in the 2021 edition of the ASME BPVC state that a Procedure Specification is a written document that provides direction to the person applying the material joining process. Details for preparation and qualification of Procedure Specifications are provided in the 2007 and 2021 editions of Section IX of the ASME BPVC for welding processes (WPS) and brazing processes (BPS), and in the 2021 editions of Section IX of the ASME BPVC for fusing (FPS) processes. According to rules specified in Section IX of the ASME BPVC, a WPS, BPS, or FPS used by an organization having responsibility for operational control of material joining processes must have been qualified by that organization or must be a standard Procedure Specification acceptable under the rules for the joining process to be used.

The Procedure Specification addresses the conditions (including ranges, if any) under which the material joining process must be performed. These conditions are referred to as “variables.” When a Procedure Specification is prepared by the organization, it must address, as a minimum, the specific essential and nonessential variables that are applicable to the material joining process to be used in production. When toughness qualification of the material joining procedure is required, the applicable supplementary essential variables must also be addressed in the Procedure Specification.

Rules for welding procedure qualification are specified in Part QW, Article II in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for brazing procedure qualification are specified in Part QB, Article XII in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for plastic fusing procedure qualification are only specified in Part QF, Article XXII in the 2021 edition of Section IX of the ASME BPVC.

5.3.4 Rules in Section IX for Procedure Qualification Record (PQR)

General requirements in Section IX, Paragraph QG-102 – Procedure Qualification Record in the 2021 edition of the ASME BPVC state that a procedure qualification record (PQR) documents what occurred during the production of a procedure qualification test coupon and the results of testing that coupon. As a minimum, the record must document the essential variables for each process used to produce the test coupon, the ranges of variables qualified, and the results of the required testing and nondestructive examinations. The organization must certify a PQR by a signature or other means as described in the organization's Quality Control System and must make the PQR accessible to the Authorized Inspector.

Rules that govern PQR are specified in Paragraph QW-200.2 for welding and QB-200.2 for brazing in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules that govern PQR for plastic fusing are specified in Paragraph QF-201.5 for in the 2021 edition of Section IX of the ASME BPVC.

5.3.5 Rules in Section IX for Performance Qualification

General requirements in Section IX, Paragraph QG-103 – Performance Qualification in the 2021 edition of the ASME BPVC state that the purpose of qualifying the person who will use a joining process is to demonstrate that person's ability to produce a sound joint when using a PS.

Rules for welding performance qualification are specified in Part QW, Article III in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for brazing performance qualification are specified in Part QB, Article XIII in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for plastic fusing performance qualification are only specified in Part QF, Article XXIII in the 2021 edition of Section IX of the ASME BPVC.

5.3.6 Rules in Section IX for Performance Qualification Record

General requirements in Section IX, Paragraph QG-104 – Performance Qualification Record in the 2021 edition of the ASME BPVC state that the performance qualification record documents what occurred during the production of a test coupon by a person using one or more joining processes following an organization's PS. As a minimum, the record shall document:

- *(a)* the essential variables for each process used to produce the test coupon.
- *(b)* the ranges of variables qualified as required by the applicable part (see QW-301.4, QB-301.4, and QF-301.4).
- *(c)* the results of the required testing and nondestructive examinations.
- *(d)* the identification of the procedure specification(s) followed during the test.

Rules for Welder/Welding Operator Performance Qualification (WPQ) are specified in Paragraph QW-301.4 in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for Brazer or Brazing Operator Performance Qualification (BPQ) are specified in Paragraph QB-301.4 in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for Fusing Operator Performance Qualification Record (FPQ) are specified in Paragraph QF-301.4 in the 2021 edition of Section IX of the ASME BPVC.

5.3.7 Rules in Section IX Welding, Brazing, and Fusing Data

Welding, brazing, and fusing data articles include the variables grouped into categories such as joints, base materials and filler materials, positions, preheat and postweld heat treatment, gas, electrical characteristics, and technique. These variables are referenced from other articles as they apply to each process.

Welding data include essential, supplementary essential, or nonessential variables. Brazing data include essential and nonessential variables. Fusing data include the fusing variables grouped as joints, pipe material, position, thermal conditions, equipment, and technique.

Rules for welding data are specified in Part QW, Article IV in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for brazing data are specified in Part QB, Article XIV in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for fusing data are only specified in Part QF, Article XXIV in the 2021 edition of Section IX of the ASME BPVC.

5.4 HEAT TREATMENT OF WELDMENTS

Heat treatment can affect the strength and toughness of a welded joint, its corrosion resistance, and the level of residual stress. Heat treatment requirements, which are material dependent, are categorized as preheating and postweld heat treatment (PWHT).

5.4.1 Preheating Requirements

Preheating requirements for welding are specified in Article IV – Welding Data Paragraph QW-406 in the 2007 and 2021 editions of the ASME BPVC. The minimum temperature for welding shall be specified in the WPS. Preheat temperature is defined as the minimum temperature in the weld joint preparation immediately prior to the welding; or in the case of multiple pass welds, the minimum temperature in the section of the previously deposited weld metal, immediately prior to welding.

5.4.1.1 Preheating Requirements in Section I

Preheating and interpass temperatures requirements are provided in Paragraph PW-38 – Preheating and Interpass Temperatures in the 2007 and 2021 editions of Section I of the ASME BPVC. According to these requirements, the WPS for the material being welded shall specify the minimum preheating and maximum interpass requirements in accordance with the rules of this Section and Section IX.

Paragraph PW-38 in the 2007 edition of Section I of the ASME BPVC was revised in its entirety in the 2021 edition to adds recommended preheat temperatures in Table PW 38-1 – Recommended Preheat Temperatures for Welding of Pressure Parts and Attachments and rules for P-No. 1 materials. These rules for preheating of P-No. 1 materials only apply when mandated by PW-39 – Requirements for Postweld Heat Treatment for exemption of postweld heat treatment. These preheating requirements in Paragraph PW-38 includes seven additional paragraphs of requirements that are not included 2007 edition of Section I.

5.4.1.2 Preheating Requirements in Section VIII, Division 1

Nonmandatory Appendix R – Preheating in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC states that preheating may be employed during welding to assist in completion of the welded joint. The need for and temperature of preheat are dependent on various factors such as the chemical analysis, degree of restraint of the parts being joined, elevated physical properties, and heavy thicknesses. Mandatory rules for preheating are, therefore, not given in this Division except as required in the footnotes that provide for exemptions to postweld heat treatment in Tables UCS-56 and UHA-32. Some practices used for preheating are given in Nonmandatory Appendix R as a general guide for the materials listed by P-Numbers in Section IX.

5.4.1.3 Preheating Requirements in Section VIII, Division 2

Requirements for preheating of welds are provided in Paragraph 6.4.1 in the in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. Guidelines for preheating are provided in Table 6.7 – Minimum Preheat Temperatures for Welding for the materials listed by P-Numbers in Section IX. It is cautioned that the preheating parameters shown in this table do not necessarily ensure satisfactory completion of the welded joint, and requirements for individual materials for the P-Number listing may have preheating requirements that are more restrictive.

5.4.2 Postweld Heat Treatment Requirements

Satisfactory qualification of the welding procedure must be performed before applying the detailed requirements and exemptions for postweld heat treatment specified in Section I; Section VIII, Division 1; and Section VIII, Division 2 of the ASME BPVC.

5.4.2.1 Postweld Heat Treatment Requirements in Section I

Requirements for postweld heat treatment are specified in Paragraph PW-39 – Requirements for Postweld Heat Treatment in the 2007 and 2021 editions of Section I of the ASME BPVC. According to requirements specified in Paragraph PW-39.1, all welded pressure parts of power boilers must be given a postweld heat treatment at a minimum hold temperature not less than that specified in Table PW-39.1 in the 2007 edition or Tables PW-39-1 through PW-39-14 in the 2021 edition. These tables in the 2021 edition apply to P-Numbers 1, 3, 4, 5A, 5B, 15E, 6, 7, 10H, 31, 43, 45, and 51 materials. Postweld heat treatment requirements in Paragraph PW-39 includes additional requirements that are not included in the 2007 edition of Section I.

Table PW-39.1 in the 2021 editions of Section I of the ASME BPVC provides alternative postweld heat treatment requirements for carbon and low alloy steels. Rules in Table PW-39-5 prescribe mandatory requirements for postweld heat treatment of pressure parts and attachments fabricated using P-No. 15E Group No. 1. Requirements in Table PW-39-5 were initiated for consistency with Section IX requirements that incorporates new Creep-Strength Enhanced Ferritic (CSEF) alloys into the ASME BPVC.

5.4.2.2 Postweld Heat Treatment Requirements in Section VIII, Division 1

Requirements for postweld heat treatment are specified in Paragraph UW-40 – Repair of Defects in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. According to rules specified in Paragraph UW-40(*a*), minimum postweld heat treatment normal holding temperatures are specified in Table UCS-56 in the 2007 edition for P-Numbers 1, 3, 4, 5A, 5B, 5C, 9A, 9B, 10A, 10B, and 10F materials and Tables UCS-56-1 through UCS-56-11 in the 2021 edition for P-Numbers 1, 3, 4, 5A, 5B, 5C, 9A, 9B, 10A, 10C, and 15E materials.

Postweld heat treatment requirements for ferritic steels with properties enhanced by heat treatment are specified in Paragraph UHT-56 – Postweld Heat Treatment in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. According to requirements specified in Paragraph UHT-56(*a*), postweld heat treatment temperature ranges are specified in Table UHT-56. This table specifies postweld heat treatment temperature ranges for P-Numbers 1, 6, 11A, and 11B materials.

Postweld heat treatment requirements for high alloy steels are specified in Paragraph UHA-32 – Requirements for Postweld Heat Treatment in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. According to requirements specified in Paragraph UHA-32(*a*), minimum postweld heat treatment normal hold temperatures are specified in Table UHA-32 in the 2007 edition and Tables UHA-32-1 through UHA-32-7 in the 2021 edition. Table UHA-32 specify minimum postweld heat treatment normal hold temperatures for P-Numbers 6, 7, 8, 10H, 10I, and 10K materials. Tables UHA-32-1 through UHA-32-7 specify minimum postweld heat treatment normal hold temperatures for P-Numbers 6, 7, 8, 10H, 10I, 10K, and 45 materials.

Postweld heat treatment of nonferrous materials is normally neither necessary nor desirable. However, postweld heat treatment requirements for those nonferrous materials identified in Paragraph UNF-56 Postweld Heat Treatment in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC are specified in Paragraph UNF-56*(c)*, *(d)*, and *(e)*.

5.4.2.3 Postweld Heat Treatment Requirements in Section VIII, Division 2

Requirements for postweld heat treatment are provided in Paragraph 6.4.2 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. In the 2007 edition, minimum postweld heat treatment holding temperatures are specified in Tables 6.8 through 6.15 for P-Numbers 1, 3, 4, 5A, 5B, 5C, 6, 7, 8, 9A, 9B, 10A, 10B, 10E, 10F, 10G, 10H, 10I, and 10K materials. Table 6.16 provides alternative postweld heat treatment requirement for carbon and low alloy steels. In the 2021 edition, minimum postweld heat treatment holding temperatures are specified in Tables 6.8 through 6.15 for P-Numbers 1, 3, 4, 5A, 5B, 5C, 15E, 6, 7, 8, 9A, 9B, 10A, 10B, 10C, 10E, 10F, 10G, 10H, 10I, 10K, and 45 materials. Table 6.16 provides alternative postweld heat treatment requirement for carbon and low alloy steels.

Postweld heat treatment requirements for quenched and tempered high strength steel materials listed in Table 3-A.2, are covered in Part 6, Paragraph 6.6.6 in Section VIII, Division 2 of the 2007 and 2021 editions of the ASME BPVC. Vessels or parts of vessels constructed of quenched and tempered steels shall be postweld heat treated when required in Table 6.17 – Postweld Heat Treatment Requirements for Quenched and Tempered Materials in Table 3-A.2 – Quenched and Tempered High Strength Steels. This table specifies postweld heat-treatment temperatures ranges for these materials.

Although postweld heat treatment of nonferrous materials is normally not necessary or desirable, postweld heat treatment requirements for specified nonferrous materials are covered in Part 6, Paragraph 6.4.6 in Section VIII, Division 2 of the 2007 and 2021 editions of the ASME BPVC. Except for exemptions specified in Paragraph 6.4.6, postweld heat treatment shall not be performed except by agreement between the purchaser and the Manufacturer.

5.5 COLD STRETCHING

Cold stretching is a pressure vessel construction method that involves fabrication of a pressure vessel from ductile material, and then subjecting the pressure vessel to a hydrostatic pressure that causes the material to plastically deform (i.e., stretch). Plastic deformation of a ductile material increases its yield strength and hardness [13], thus reducing the required wall thickness of the pressure vessel. Austenitic stainless steels are excellent materials for cold stretching applications because they exhibit considerable work-hardening properties while still maintaining many other desirable qualities. For most austenitic stainless steels, the strain corresponding to the tensile strength is 30% or more.

Cold stretching in the United States was introduced as Code Case 2596 on January 29, 2008 and was later incorporated into the 2013 edition of Section VIII Division 1 of the ASME BPVC. The inquiry reply in Code Case 2596 states:

> *It is the opinion of the Committee that cold-stretched austenitic stainless steel vessels may be designed and fabricated under the rules of Section VIII, Division 1, provided the following additional requirements are met.*

These additional requirements are codified in Mandatory Appendix 44 – Cold Stretching of Austenitic Stainless Steel Pressure Vessels in the 2021 edition of Section VIII, Division 1 of the ASME BPVC. The cold stretching method as defined in Code Case 2596 and codified in Mandatory Appendix 44 involves the following sequential activities.

1. Design the austenitic stainless steel pressure vessel based on a maximum allowable stress, σ_k for the material determined as follows:

$$\sigma_k = (\text{specified yield strength } + \text{ 29 ksi}) \ / \ 1.5$$

2. Construct the pressure vessel in accordance with rules specified in Section VIII, Division 1.
3. Pressurize the completed pressure vessel to a cold-stretching pressure, P_c, between 1.5 and 1.6 times the design pressure, P.
4. Mark the nameplate with "CS" under the Certification Mark indicating the vessel was constructed using cold-stretching methods. In addition, the Manufacturer shall indicate in the Remarks section of the Manufacturer's Data Report: "This vessel has been constructed using cold-stretching processes in accordance with Mandatory Appendix 44."

Subjecting an austenitic stainless steel pressure vessel to an internal pressure between 1.5 P and 1.6 P is sufficient to cause a permanent change in the diameter of the pressure vessel due to plastic deformation of the material. The amount of plastic deformation the pressure vessel exhibits is a function of the actual yield strength of the material and the material's non-linear stress-strain relationship.

5.5.1 Summary of Cold Stretching Requirements in Section VIII, Division 1

Mandatory Appendix 44 in the 2021 edition of Section VIII, Division 1 of the ASME BPVC specifies requirements for design, construct, and stamping of cold-stretched austenitic stainless steel pressure vessels in addition to those provided in Section VIII, Division 1. However, rules in Paragraph 44-4 restrict design and fabrication of cold-stretched pressure vessels to those austenitic stainless steels listed in Table 5.4 of this report.

Table 5.4 Materials permitted for construction of cold-stretched austenitic stainless-steel pressure vessels

Material SA-240/SA-240M Stainless Steel†	Allowable Design Stress, *S*, in Tension, ksi (MPa)‡	Yield Strength, ksi (MPa), min.	Tensile Strength, ksi (MPa), min.	Elongation, %, min.
Type 304	39.3 (270)	30 (205)	75 (515)	40
Type 304L	36.0 (247)	25 (170)	70 (485)	40
Type 304N	42.7 (293)	35 (240)	80 (550)	30
Type 304LN	39.3 (270)	30 (205)	75 (515)	40
Type 316	39.3 (270)	30 (205)	75 (515)	40
Type 316L	36.0 (247)	25 (170)	70 (485)	40
Type 316N	42.7 (293)	35 (240)	80 (550)	30
Type 316LN	39.3 (270)	30 (205)	75 (515)	40

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

‡The allowable design stress equals the sum of the yield strength plus 29 ksi divided by 1.5.

For reference, Table 5.4 of this report also includes allowable design stresses based on rules specified in Mandatory Appendix 44 and the minimum yield strength, tensile strength, and elongation values specified in SA-240/SA-240M for these materials.

Design rules specified in Paragraph 44-5 in Mandatory Appendix 44 in the 2021 edition of Section VIII, Division 1 of the ASME BPVC state that the wall thickness of a cold stretched pressure vessel is calculated according to the applicable rules of Section VIII, Division 1 before cold stretching using the applicable allowable design stress value shown in Table 5.4 of this report. Other restrictions on the design and fabrication of cold stretched pressure vessels include:

- vessel wall ≤ 1.2 in.
- design calculations are based on the nominal diameter – no allowance is necessary for the possible increase in diameter due to cold stretching
- MDMT ≥ -320°F
- maximum design temperature ≤ 120°F
- rules are limited to single diameter cylindrical shells with dished heads or spherical shells – flat heads are not permitted
- rules are only applicable for internal pressure
- minimum specified ultimate tensile strength (UTS) of weld filler metal must not be less than the minimum specified UTS for the base metals of the weld joint
- radiographic examination must be performed before cold stretching

Rules to assure adequate toughness include:

- impact testing of base materials is not required
- welding procedure qualification must include impact tests of weld metal and heat affected zone at MDMT in the cold stretched condition at 1.5 time the allowable design stress, *S*

- welding procedure qualification is exempted from impact testing for MDMT of -55°F and warmer

Fabrication process rules that cover welding and examination, cold-stretching operation, and cold-stretching procedure record are provided in Mandatory Appendix 44, Paragraph 44-6 in the 2021 edition of Section VIII, Division 1 of the ASME BPVC.

5.5.2 Cold Stretching Technology

Cold stretching is permitted because it takes advantage of the strain hardening characteristics, toughness, and ductility of austenitic stainless steels. Points A through E in Fig. 5.1 of this report show an idealized stress-strain curve for Type 304L stainless steel that conforms to applicable minimum yield strength, tensile strength, and elongation requirements specified in material specification SA-240/SA-240M.

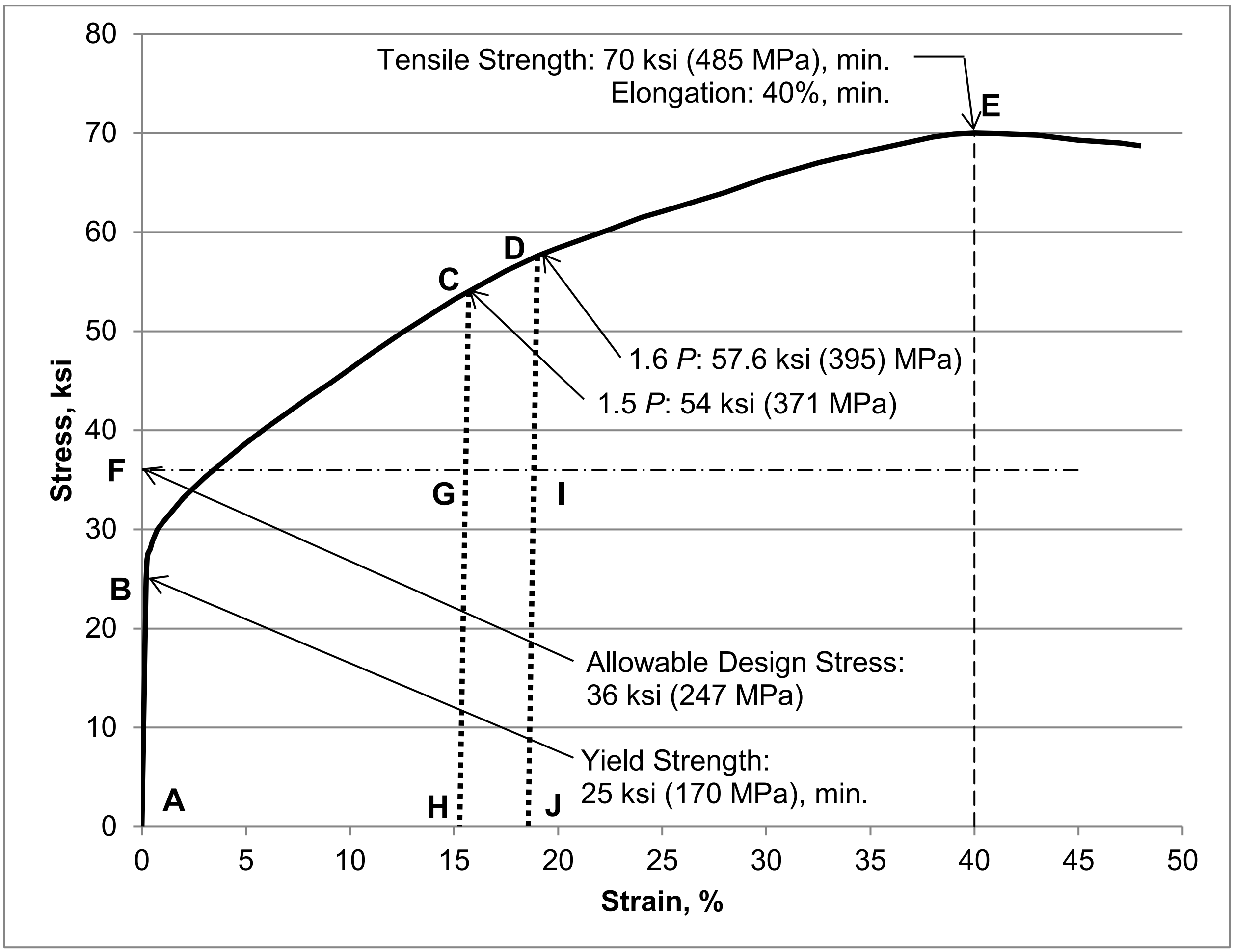

Fig. 5.1 Idealized stress-strain relationship for Type 304L stainless steel

According to rules specified in Mandatory Appendix 44, Paragraph 44-5 in the 2021 edition of Section VIII, Division 1 of the ASME BPVC, the allowable design stress for SA-240, Type 304L stainless steel is 36 ksi (i.e., [(25 + 29) / 1.5]). This value, which exceeds the minimum specified yield strength indicated by Point B, corresponds to Point F in Fig. 5.1 of this report. The required wall thickness of a pressure vessel is determined using this allowable design stress, *S*, and the design pressure, *P*.

Following construction, the pressure vessel is subjected to a cold-stretching pressure, P_c, which must be between 1.5 P and 1.6 P. These limits correspond to Points C and D, respectively, in Fig. 5.1 of this report. The tensile stress resulting from a cold-stretching pressure equal to 1.5 P is 54 ksi. The tensile stress resulting from a cold-stretching pressure equal to 1.6 P is 57.6 ksi.

As the pressure is vented following completion of the cold-stretching operation, the tensile stress in the wall decreases linearly from Point C or D to atmospheric pressure along the path shown by Lines CGH and DIJ, respectively, in Fig. 5.1 of this report. The slope of these paths is governed by the modulus of elasticity of the material.

After the pressure vessel is placed in service and subjected to the design pressure, P, the tensile stresses in the wall exhibit linearly elastic stress-strain behavior as shown by Line GH or IJ in Fig. 5.1 of this report. The specific path depends on the magnitude of the cold-stretching pressure, P_c. In the cold-stretching method, the minimum design margin against plastic collapse is at least 1.5 (i.e., ratio of stress at point C, 54 ksi, versus stress at point G, 36 ksi) which is consistent with the limit design theory principles discussed in Sect. 4.6 of this report.

The cold-stretched base materials listed in Table 44-4-1 need not be impact tested when used in vessels constructed in accordance with this Mandatory Appendix 44. Adequate fracture toughness of cold-stretched pressure vessels is provided by:

- limiting the wall thickness of cold-stretched pressure vessels to 1.2 in.
- including impact testing in the welding procedure qualification. When the MDMT is colder than -55°F (-48°C), the WPQ shall include impact tests of welds and heat-affected zones (HAZs).
- limiting construction of cold-stretched pressure vessels to specific SA-240/SA-240M stainless steels (these stainless steels exhibit lateral expansion greater than 0.015 in. at -320°F.).
- requiring a minimum design metal temperature, no colder than -320°F.
- limiting the design temperature to 120°F or less.

5.6 QUALITY CONTROL

The ASME BPVC requires any Manufacturer or Assembler holding or applying for a Certificate of Authorization to use the Certification Mark to have, and demonstrate, a quality control system to establish that all Code requirements, including material, design, fabrication, examination (by the Manufacturer), inspection of boilers, pressure vessels, and associated parts (by the Authorized Inspector), pressure testing, and certification will be met. The Authorized Inspector is responsible for verifying that the Manufacturer has a valid Certificate of Authorization and is working to a quality control system.

Section I; Section VIII, Division 1; and Section VIII, Division 2 of the ASME BPVC provide guidance and requirements for the scope and content of the quality control system. It is important to note that the quality control system may contain information of proprietary nature relating to the Manufacturer's processes. Therefore, the ASME BPVC does not require any distribution of this information, except for the Authorized Inspector or an ASME designee.

5.6.1 Quality Control System Requirements in Section I

Quality control system requirements are provided in Paragraph PG-105.4 in the 2007 and 2021 editions of Section I of the ASME BPVC. Paragraph PG-105.4 in the 2007 state that the quality control system shall be in accordance with the requirements of A-300. Whereas Paragraph PG-105.4 in the 2021 edition state:

Any Manufacturer or Assembler holding or applying for a Certificate of Authorization shall demonstrate a quality program that meets the requirements of ASME CA-1 and establishes that all Code requirements including material, design, fabrication, examination (by the Manufacturer), and inspection for boilers and boiler parts (by the Authorized Inspector) will be met. The quality control system shall be in accordance with the requirements of A-301 and A-302.

Publication ASME CA-1 [2], which was issued in 2020, specifies requirements for accreditation and certification of organizations supplying products or services that are intended to conform to the requirements of ASME standards listed in Table 1 – ASME Certification Programs. Table 1 in ASME CA-1 assigns the ASME Certification Designator "S – Power Boilers" to Section I of the ASME BPVC. Publication ASME CA-1 was initially issued in 2013.

Quality control system requirements are provided in Nonmandatory Appendix A – Explanation of the Code Containing Matter Not Mandatory Unless Specifically Referred to in the Rules of the Code, Paragraphs A-301 – General and A-302 – Outline of Features to be Included in the Written Description of the Quality Control System in the 2021 editions of Section I of the ASME BPVC.

5.6.2 Quality Control System Requirements in Section VIII, Division 1

Quality control system requirements are provided in Paragraph UG-117(*e*) – Quality Control System in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. This paragraph in the 2021 edition of Section VIII, Division 1 states that any Manufacturer holding or applying for a Certificate of Authorization shall demonstrate a quality control program that meets the requirements of ASME CA-1 and establishes that all Code requirements, including material, design, fabrication, examination (by the Manufacturer), inspection of vessel and vessel parts (by the Authorized Inspector or Certified Individual, as applicable), pressure testing, and certification, will be met. The Quality Control System shall be in accordance with the requirements of Mandatory Appendix 10 – Quality Control System. Rules specified in Paragraph UG-91*(a)(2)* state that all Inspectors shall have been qualified in accordance with ASME QAI-1, *Qualifications for Authorized Inspection*.

Publication ASME CA-1 [2] specifies requirements for accreditation and certification of organizations supplying products or services that are intended to conform to the requirements of ASME standards listed in Table 1 – ASME Certification Programs. Table 1 in ASME CA-1 assigns the ASME Certification Designator "U – Pressure Vessel, Division 1" to Section VIII, Division 1 of the ASME BPVC. Publication ASME CA-1 was initially issued in 2013.

An outline of features to be included in the written description of the quality control system is provided in Mandatory Appendix 10, Paragraph 10-2 – Outline of Features to be Included in the Written Description of the Quality Control System. The features to be included in the written description of the quality control system are described in Paragraphs 10-3 through 10-17. Additional quality control system requirements specified in the 2021 edition of Section VIII, Division 1 of the ASME BPVC follow.

Paragraph UG-11*(e)(2)* states that the Certificate Holder's quality control system must provide for the following activities associated with subcontracting of welding operations, and these provisions must be acceptable to the Manufacturer's Authorized Inspection Agency:

- *(a)* the welding processes permitted by this Section that are permitted to be subcontracted
- *(b)* welding operations
- *(c)* Authorized Inspection activities
- *(d)* placement of the Certificate Holder's marking in accordance with UG-11*(d)(8)*

Paragraph UG-11*(e)(7)* states that the Certificate Holder and the subcontractor shall describe in their quality control systems the operational control of procedure and personnel qualifications of the subcontracted welding operations.

Paragraph UG-11*(e)(9)* states that the Certificate Holder shall describe in their Quality Control Systems the operational control for maintaining traceability of materials received from the subcontractor.

5.6.3 Quality Control System Requirements in Section VIII, Division 2

Quality control system requirements are provided in Part 2 – Responsibilities and Duties, Paragraph 2.3.6 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. Both paragraphs state that the Manufacturer shall have and maintain a Quality Control System in accordance with Annex 2-E – Quality Control System. According to requirements provided in Annex 2-E, the Manufacturer shall have and maintain a quality control system that establishes that all Code requirements, including material, design, fabrication, examination (by the Manufacturer), and inspection of vessels and vessel parts (by the Inspector), will be met. An outline of features to be addressed in a written description of the quality control system is provided in Paragraph 2-E.2. Some of these features of a quality control system, which are equally applicable to both shop and field work, follow.

- The information associated with 2.3 – Manufacturer's Responsibilities and Annex 7-A – Responsibilities and Duties for Inspection and Examination Activities.
- The complexity of the work includes factors such as design simplicity versus complexity, the types of materials and welding procedures used, the thickness of materials, the types of nondestructive examinations applied, and whether heat treatments are applied.
- The size and complexity of the Manufacturer's organization includes factors such as the number of employees, the experience level of employees, the number of vessels produced, and whether the factors defining the complexity of the work cover a wide or narrow range.

Guidelines for the features to be included in the written description of the quality control system are described in Annex 2-E, Paragraphs 2-E.3 through 2-E.16 in the 2021 edition of Section VIII, Division 2 of the ASME BPVC. Guidelines in Paragraphs 2-E.10 – Nondestructive Examination states that the quality control system should include provisions for identifying nondestructive examination procedures the Manufacturer or Assembler will apply to conform to the requirements of this Division.

Rules specified in Annex 2-G – Obtaining and Using Certification Mark Stamps in the 2021 edition of Section VIII, Division 2 of the ASME BPVC state that any Manufacturer holding or applying for a Certificate of Authorization shall demonstrate a quality control system that meets the requirements of ASME CA-1 and Annex 2-E.

Publication ASME CA-1 [2] specifies requirements for accreditation and certification of organizations supplying products or services that are intended to conform to the requirements of ASME standards listed in Table 1 – ASME Certification Programs. Table 1 in ASME CA-1 assigns the ASME Certification Designator "U2 – Pressure Vessel, Division 2" to Section VIII, Division 2 of the ASME BPVC. Publication ASME CA-1 was initially issued in 2013.

6. INSPECTIONS, TESTS, AND EXAMINATIONS

The ASME BPVC provides requirements for inspections, tests, and examinations including nondestructive examinations of boilers and pressure vessels during and after fabrication but before being placed in service. The terms inspection, examination, and nondestructive examination are defined as follows.

Inspection: the observation of any operation performed on materials and/or components to determine its acceptability in accordance with given criteria.

Examination: the process of determining the condition of an area of interest by nondestructive means against established acceptance or rejection criteria.

Nondestructive Examination (NDE): the development and application of technical methods to examine materials and/or components in ways that do not impair future usefulness and serviceability in order to detect, locate, measure, interpret, and evaluate flaws.

6.1 GENERAL INSPECTION, TEST, AND EXAMINATION REQUIREMENTS

General requirements for inspections, tests, and examinations are provided in Paragraphs PG-90 through PG-99 in Section I, Paragraphs UG-90 through UG-103 in Section VIII, Division 1, and Part 7 and Annex 7-A in Section VIII, Division 2 in the 2007 and 2021 editions of the ASME BPVC. These general requirements define Manufacturer responsibilities and Inspector duties where the terms Manufacturer, Inspector, and User are defined as follows.

Manufacturer: the organization responsible for construction of a boiler, pressure vessel, vessel component, or part or the organization responsible for the manufacture of pressure relief devices in accordance with the rules of the ASME BPVC and who holds an ASME Certificate of Authorization to apply the Certification Mark to such an item.

Inspector: an Authorized Inspector regularly employed by an ASME accredited Authorized Inspection Agency (AIA) or by a company that manufacturers pressure vessels exclusively for its own use and not for resale that is defined as a User-Manufacturer. This is the only instance in which an Inspector may be in the employ of the Manufacturer.

User: the organization that purchases the finished pressure vessel for its own use or as an agent for the owner. The user's designated agent may be either a design agency specifically engaged by the user, the Manufacturer of a system for a specific service which includes a pressure vessel as a part and which is purchased by the user, or an organization which offers pressure vessels for sale or lease for specific services. User responsibilities are discussed in Sects. 4.2.2 and 4.2.3 of this report.

Manufacturer responsibilities include, but are not limited to, the following.

- examination of all materials before fabrication to make certain they have the required thickness, to detect defects, to make certain the materials are permitted by the ASME BPVC, and that traceability to the material identification has been maintained. (See Sect. 3.1 of this report.)
- documentation of impact tests when such tests are required. (See Sect. 4.1.3 of this report.)
- examination of the shell and head sections to confirm they have been properly formed to the specified shapes within the permissible tolerances. (See Sect. 5.2 of this report.)
- qualification of the welding and brazing procedures before they are used in fabrication. (See Sect. 5.3.4 of this report.)
- qualification of welders and welding operators and brazers before using the welders or brazers in production work. (See Sect. 5.3.5 of this report.)

- examination of all parts prior to joining to make certain they have been properly fitted for welding or brazing and that the surfaces to be joined have been cleaned and the alignment tolerances are maintained.
- provision for training, experience, qualification, and certification of NDE personnel.
- examination of parts as fabrication progresses, for material marking, that defects are not evident, and that dimensional geometries are maintained.
- provision of controls to assure that all required heat treatments are performed. (See Sect. 5.4 of this report.)
- provision of records of nondestructive testing examinations. (See Sect. 6.3 of this report.)
- making the required hydrostatic or pneumatic test and having the required inspections performed during such test. (See Sect. 7.1 of this report.)
- providing for retention of radiographs, ultrasonic test reports, NDE records, Manufacturer's Data Reports, and other required documentation.

Inspector duties include, but are not limited to, the following.

- verifying that the Manufacturer has a valid Certificate of Authorization and is working to a Quality Control System (See Sect. 5.6 of this report.).
- verifying that the applicable design calculations are available.
- verifying that materials used in the construction comply with the requirements.
- verifying that all welding and brazing procedures are qualified.
- verifying that all welders, welding operators, brazers, and brazing operators are qualified.
- verifying that the heat treatments, including PWHT, are performed.
- verifying that material imperfections repaired by welding are acceptably repaired.
- verifying that weld defects are acceptably repaired.
- verifying that required NDE, impact tests, and other tests are performed and that the results are acceptable.
- making a visual inspection to confirm that there are no material or dimensional defects.
- making a visual inspection to confirm that the material identification numbers are properly transferred.
- performing internal and external inspections and witnessing the hydrostatic or pneumatic test.
- verifying that the required marking is provided and that the required nameplate is attached.
- signing the Certificate of Inspection on the Manufacturer's Data Report.

Guidance to the responsibilities of the user and designated agent are provided in Nonmandatory Appendix NN in Section VIII, Division 1 in the 2021 edition of the ASME BPVC as discussed in Sect. 4.2.2 this report. User responsibilities are provided in Part 2 – Responsibilities and Duties, Paragraph 2.2 in Section VIII, Division 2 in the 2021 edition of the ASME BPVC as discussed in Sect. 4.2.3 this report.

6.2 NONDESTRUCTIVE EXAMINATION (NDE) REQUIREMENTS

Nondestructive examination is an indispensable inspection method for assuring sound construction by identifying critical flaws in materials and welds. Section V of the ASME BPVC provides requirements and methods for NDE, which are Code requirements to the extent they are specifically referenced and required by other ASME BPVC Sections. However, some Construction Codes in the ASME BPVC only reference certain requirements and methods for NDE provided in Section V. Descriptions of NDE methods and respective abbreviations used in Section I; Section VIII, Division 1; and Section VIII, Division 2 of the ASME BPVC follow.

ET — Electromagnetic (Eddy Current): Eddy current testing is a nondestructive method of locating discontinuities in a product. Signals can be produced by discontinuities located either on the external or internal surface of the tube or by discontinuities totally contained within the walls. Since the density of eddy currents decreases nearly exponentially as the distance from the external surface increases, the response to deep-seated defects decreases.

RT — Radiography: a method of detecting imperfections in materials by passing X-ray or nuclear radiation through the material and presenting their image on a recording medium.

UT — Ultrasonics: a method for detecting imperfections in materials by passing ultrasonic vibrations (frequencies normally 1 MHz to 5 MHz) through the material.

MT — Magnetic Particle: a method of detecting cracks and similar imperfections at or near the surface in iron and the magnetic alloys of steel. It consists of properly magnetizing the material and applying finely divided magnetic particles that form patterns indicating the imperfections.

PT — Liquid Penetrant: a method of nondestructive examination that provides for the detection of imperfections open to the surface in ferrous and nonferrous materials that are nonporous.

VT — Visual: a nondestructive examination method used to evaluate an item by observation, such as, the correct assembly, surface conditions, or cleanliness of materials, parts, and components used in the fabrication and construction of ASME Code boilers, pressure vessels, and related hardware.

These NDE methods are categorized as either surface examinations or volumetric examinations. Surface NDE is a method capable of detecting imperfections located on or just beneath the surface of a component. Surface examination methods include ET, PT, MT, and VT. Volumetric NDE is a method capable of detecting imperfections located anywhere within the examined volume. Volumetric examination methods include RT and UT. Discussions of underlying NDE technologies for these methods are presented in Sect. 6.3 of this report.

6.2.1 General NDE Requirements in Section I

Rules for circumferential and longitudinal butt-welded joints in boilers that are fabricated by welding and require volumetric examination are specified in Paragraph PW-11 – Requirements for Boilers Fabricated by Welding in the 2007 and 2021 editions of Section I of the ASME BPVC. These rules state that all circumferential and longitudinal butt-welded joints must be examined throughout their entire length unless specifically exempted by rules that depend on the service conditions, nominal pipe size, or material thickness. The following statement in Paragraph PW-11 in the 2007 and 2021 editions of Section I of the ASME BPVC establishes the basis for these exemptions.

Experience has demonstrated that welded butt joints not requiring volumetric examination by these rules have given safe and reliable service even if they contain imperfections that may be disclosed upon further examination. Any examination and acceptance standards beyond the requirements of this Section are beyond the scope of this Code and shall be a matter of agreement between the Manufacturer and the User.

Rules specified in Paragraph PW-11 further define which volumetric examination method (RT or UT) or combination of methods (RT and UT) must be used to examine particular types of circumferential and longitudinal butt-welded joints as discussed in Sects. 6.2.1.1 and 6.2.1.2 of this report.

Inspection and tests requirements specified in Paragraph PW-93 – Examination and Repair of Flat Plate in Corner Joints in the 2007 and 2021 editions of Section I of the ASME BPVC require examinations after welding by either the magnetic particle (MT) or liquid penetrant (PT) method. Methods and acceptance criteria for magnetic particle and liquid penetrant examination must be in accordance with Paragraph A-260 or A-270 in Nonmandatory Appendix A – Explanation of the Code Containing Matter Not Mandatory Unless Specifically Referred to in the Rules of the Code Paragraph, respectively.

Rules for visual and liquid penetrant examinations (VT and PT) of bimetallic tubes when the clad strength is included are specified in Paragraph PW-44 in the 2021 edition of Section I of the ASME BPVC as discussed in Sects. 6.2.1.4 and 6.2.1.5, respectively, of this report. Corresponding rules for bimetallic tubes are not included in Paragraph PW-44 in the 2007 edition of Section I of the ASME BPVC.

Qualification requirements for NDE personnel that perform radiographic or ultrasonic examinations are provided in Paragraph PW-50 – Radiographic Examination in the 2007 and 2021 editions of Section I of the ASME BPVC.

Paragraphs PW-50.1, 50.2, and 50.3 in the 2007 edition states:

> PW-50.1 *The Manufacturer shall be responsible for assuring that nondestructive examination (NDE) personnel have been qualified and certified in accordance with their employer's written practice prior to performing or evaluating radiographic or ultrasonic examinations required by this Section. SNT-TC-1A or CP-189 (2001 editions) shall be used as a guideline for employers to establish their written practice. National or international Central Certification Programs, such as the ASNT Central Certification Program (ACCP), may be used to fulfill the examination and demonstration requirements of the employer's written practice. Provisions for training, experience, qualification, and certification of NDE personnel shall be described in the Manufacturer's quality control system (See PG-105.4).*
>
> PW-50.2 *NDE personnel shall be qualified by examination. Qualification of NDE Level III personnel certified prior to the 2004 Edition of Section I may be based on demonstrated ability, achievement, education, and experience. Such qualification shall be specifically addressed in the written practice. When NDE personnel have been certified in accordance with a written practice based on an edition of SNT-TC-1A or CP-189 earlier than that referenced in A-360, their certification shall be valid until their next scheduled recertification.*
>
> PW-50.3 *Recertification shall be in accordance with the employer's written practice based on the edition of SNT-TC-1A or CP-189 referenced in A-360. Recertification may be based on evidence of continued satisfactory performance or by reexamination(s) deemed necessary by the employer.*

Paragraphs PW-50.1, 50.2, and 50.3 in the 2021 edition states:

> *The Manufacturer shall be responsible for assuring that nondestructive examination (NDE) personnel have been qualified and certified in accordance with their employer's written practice prior to performing or evaluating radiographic or ultrasonic examinations required by this Section. SNT-TC-1A or CP-189 (2006 editions) shall be used as a guideline for employers to establish their written practice. If the techniques of computed radiography (CR), digital radiography (DR), phased array ultrasonic testing (PAUT), or ultrasonic time-of-flight diffraction (TOFD) are used, the training, experience, and examination requirements in Section V, Article 1, Mandatory Appendix II shall also be included in the employer's written practice for each technique as applicable. National or international Central Certification Programs may be used to fulfill the examination and demonstration requirements of the employer's written practice. Provisions for training, experience, qualification, and certification*

of NDE personnel shall be described in the Manufacturer's quality control system (see PG-105.4).

PW-50.2 NDE personnel shall be qualified by examination. Qualification of NDE Level III personnel certified prior to the 2004 Edition of Section I may be based on demonstrated ability, achievement, education, and experience. Such qualification shall be specifically addressed in the written practice. If the NDE Level III personnel are certified in either the RT or UT methods and uses the techniques of computed radiography (CR), digital radiography (DR), phased array ultrasonic testing (PAUT), or ultrasonic time-of-flight diffraction (TOFD), then prior to their next recertification period, the requirements in Section V, Article 1, Mandatory Appendix II for Level III personnel shall also be met. When NDE personnel have been certified in accordance with a written practice based on an edition of SNT-TC-1A or CP-189 earlier than that referenced in A-360, their certification shall be valid until their next scheduled recertification.

PW-50.3 Recertification shall be in accordance with the employer's written practice based on the edition of SNT-TC-1A or CP-189 referenced in A-360. Recertification may be based on evidence of continued satisfactory performance or by reexamination(s) deemed necessary by the employer. In addition, if the techniques of computed radiography (CR), digital radiography (DR), phased array ultrasonic testing (PAUT), or ultrasonic time-of- flight diffraction (TOFD) are used, the training, experience, and examination requirements in Section V, Article 1, Mandatory Appendix II shall be met by NDE personnel prior to recertification.

Note the difference in SNT-TC-1A or CP-189 editions (i.e., 2001 vs 2006) prescribed in Paragraph PW-50.1 in the 2007 and 2021 editions of Section I of the ASME BPVC.

Qualifications for nondestructive examination personnel that perform magnetic particle and liquid penetrant examinations are provided in Nonmandatory Appendix A – Explanation of the Code Containing Matter Not Mandatory Unless Specifically Referred to in the Rules of the Code, Paragraphs A-260 and A-270, respectively, in the 2007 and 2021 editions of Section I of the ASME BPVC. Requirements for certification of personnel that perform magnetic particle and liquid penetrant examinations are provided in Paragraphs A-260.2 and A-270.2, respectively. Requirements in these paragraphs state that the Manufacturer shall certify that each magnetic particle examiner meets the following requirements:

(a) The examiner has vision, with correction if necessary, to enable him to read a Jaeger Type No. 2 Standard Chart at a distance of not less than 12 in. (300 mm) and is capable of distinguishing and differentiating contrast between colors used. These capabilities shall be checked annually.

(b) The examiner is competent in the techniques of the magnetic particle examination method for which he is certified, including making the examination and interpreting and evaluating the results, except that where the examination method consists of more than one operation, he may be certified as being qualified only for one or more of these operations.

6.2.1.1 Radiographic Examination Requirements in Section I

Rules for radiography examination of welds are provided in Paragraph PW-51 – Radiographic Examination in the 2007 and 2021 editions of Section I of the ASME BPVC. These rules state that all welds that require radiographic examination must be examined by the X-ray or gamma-ray method in accordance with rules specified in Article 2 – Radiographic Examination, Section V of the ASME BPVC. Paragraphs PW-51.3.1 and PW-51.3.2 in both editions define the conditions under which indications shown on the radiographs of welds and characterized as imperfections are unacceptable and must be repaired and the repair radiographed. Acceptance standards for radiographic examinations are compared in Sect. 6.2.4.1 of this report.

Welded-butt joints that require volumetric examination are specified in Table PW-11 – Required Volumetric Examination of Welded Butt Joints in the 2007 and 2021 editions of Section I of the ASME BPVC. These volumetric examination requirements vary depending on the pressure part service conditions but otherwise cover the entire length of all longitudinal butt-welded joints (all sizes and thicknesses) and circumferential welds in pressure parts that exceed NPS 10 or 1.25 in. wall thickness.

6.2.1.2 Ultrasonic Examination Requirements in Section I

Rules for ultrasonic examination of welds are provided in Paragraph PW-52 – Ultrasonic Examination in the 2007 and 2021 editions of Section I of the ASME BPVC. The rules in Paragraph PW-52.1 state that technique and standards for ultrasonic examination shall follow Section V, Article 4. However, the rules in Paragraph PW-52.1 in the 2021 edition further state that techniques and standards for ultrasonic examination must follow rules specified in Section V, Article 4, Mandatory Appendix VII – Ultrasonic Examination Requirements for a Workmanship Based Acceptance Criteria. As an alternative, Nonmandatory Appendix E – Alternative Method for Ultrasonic Examination may be used for the ultrasonic examination of welds requiring volumetric examination by PW-11 – Volumetric Examination of Welded Butt Joints.

Paragraph PW-11.1 state that unless Table PW-11 restricts volumetric examination to one method, either the radiographic or the ultrasonic method may be used. Acceptance of the weld shall be determined by the method selected for the initial examination of the completed weld. Acceptance standards for ultrasonic examinations are compared in Sect. 6.2.4.1 of this report.

6.2.1.3 Magnetic Particle Examination Requirements in Section I

Requirements for magnetic particle examination of welds are provided in Paragraph PG-93 – Examination and Repair of Flat Plate in Corner Joints in the 2007 and 2021 edition of Section I of the ASME BPVC. Paragraph PG-93.3 states that methods and acceptance criteria for magnetic particle and liquid penetrant examination shall be in accordance with Paragraph A-260 in Nonmandatory Appendix A – Explanation of the Code Containing Matter Not Mandatory Unless Specifically Referred to in the Rules of the Code.

Nonmandatory Appendix A provides procedures that must be followed whenever magnetic particle examination is required by Paragraph PG-93. The detailed examination method of Section V, Article 7 – Magnetic Particle Examination must be used with the acceptance criteria specified in this appendix. Magnetic particle examination must be performed in accordance with a written procedure, demonstrated to the satisfaction of the Inspector, and certified by the Manufacturer to be in accordance with the requirement of Section V, Article 1 – General Requirements, T-150*(a)* or T-150*(b)*.

6.2.1.4 Liquid Penetrant Examination Requirements in Section I

Procedures to be followed whenever liquid penetrant examination is required by Paragraph PG-93 in the 2007 and 2021 editions of Section I of the ASME BPVC. The detailed examination method of Section V, Article 6 shall be used with the acceptance criteria specified in this Appendix. Liquid penetrant examination shall be performed in accordance with a written procedure, demonstrated to the satisfaction of the Inspector, and certified by the Manufacturer to be in accordance with the requirement of Section V, Subsection A, Article 1, T-150*(a)* or T-150*(b)*.

Fabrication rules for bimetallic tubes when the clad strength is included are specified in Paragraph PW-44.8.1 in the 2021 edition of Section I of the ASME BPVC. These rules state:

Visual examination (VT) shall be performed on 100% of the clad surface in accordance with Section V, Article 9. Any indication open to the surface shall additionally be subjected to liquid penetrant examination (PT) in accordance with A-270 and acceptance or rejection based on A-270.4. The portion of bimetallic tubing containing rejectable defects shall either be removed or the defects repaired in accordance with PW-44.9.

Corresponding rules for fabrication of bimetallic tubes when the clad strength is included are not provided in the 2007 edition of Section I of the ASME BPVC.

6.2.1.5 Visual Examination Requirements in Section I

As discussed in Sect. 6.2.1.4 of this report, fabrication rules for bimetallic tubes when the clad strength is included, which are specified in Paragraph PW-44.8.1, require visual examination on 100% of the clad surface in accordance with Section V, Article 9 – Visual Examination as discussed in Sect. 6.3.7 of this report.

Fabrication requirements specified in Paragraph PG-75 – General in the 2021 edition of Section I of the ASME BPVC states that unless otherwise required to verify compliance with specific parts of this Section, visual examination shall be performed to verify compliance with applicable requirements for dimensions, joint preparation, and alignment prior to welding or joining, and finished weld conditions, as follows:

- *(a)* Visual examination shall be confined to the portions of the assembly that are exposed to unobstructed observation with the unaided eye (or with corrective lenses). This is normally performed when access is sufficient to place the eye within approximately 24 in. (600 mm) of the surface to be examined and at an angle not less than approximately 30 deg to the surface to be examined. Mirrors may be used to achieve a view of the component to be examined.
- *(b)* Lighting of the area being examined must be adequate to provide clear observation, with no shadows and essentially free of glare. Supplementary lighting may be used where natural lighting is inadequate for proper examination.
- *(c)* The area under observation shall be clean and free of all “loose” foreign materials such as scale, sand, weld spatter and slag, cutting chips, etc.
- *(d)* At the discretion of the Manufacturer or the Inspector, supplemental visual examination methods may be used to verify acceptability of suspect areas.
- *(e)* At the option of the Manufacturer, visual examination may be performed in accordance with Section V, Article 9 – Visual Examination.

Corresponding requirements in Paragraph PG-75 are not specified in the 2007 edition of Section I of the ASME BPVC.

6.2.2 General NDE Requirements in Section VIII, Division 1

Rules for volumetric and surface examinations of joints in pressure vessels that are fabricated by welding and require examination are specified in Paragraphs UW-11 – Radiographic and Ultrasonic Examination and UG-103 – Nondestructive Testing, respectively, in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC.

Rules in Paragraph UW-11 – Radiographic and Ultrasonic Examination in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC require radiographic and ultrasonic examinations of welded joints as specified in the following paragraphs.

- UW-11(*a*) – full radiography (2007 and 2021 editions)
- UW-11(*b*) – spot radiography (2007 and 2021 editions)
- UW-11(*c*) – no radiography (2007 and 2021 editions)
- UW-11(*d*) – electrogas welds in ferritic materials (2007 and 2021 editions)
- UW-11(*e*) – welds made by the electron beam or laser beam process (2021 edition)
- UW-11(*f*) – welds made by the inertia and continuous drive friction welding process (2021 edition)

A summary of requirements specified in Paragraph UW-11 in the 2021 editions of Section VIII, Division 1 of the ASME BPVC for each type of examination follows.

(a) Butt joints that must be subjected to radiographic examination over their full length are identified in Paragraph UW-11*(a)*. Paragraph UW-11*(a)(7)* in the 2007 edition states that ultrasonic examination in accordance with UW-53 – Ultrasonic Examination of Welded Joints may be substituted for radiography for the final closure seam of a pressure vessel if the construction of the vessel does not permit interpretable radiographs in accordance with Code requirements. However, Paragraph UW-11(*a*) in the 2021 edition does not permit substitution of ultrasonic examination for radiography for the final closure seam of a pressure vessel. Butt joints subjected to full radiography are permitted to have higher joint design efficiencies compared to butt joints subjected to spot radiography.

(b) According to rule specified in Paragraph UW-11*(b)*, Except when spot radiography is required for Category B or C butt welds by *(a)(5)(-b)* above, butt-welded joints made in accordance with Type No. (1) or (2) of Table UW-12 – Maximum Allowable Joint Efficiencies for Welded Joints which are not required to be fully radiographed by *(a)* above, may be examined by spot radiography. Spot radiography shall be in accordance with UW-52 – Spot Examination of Welded Joints. If spot radiography is specified for the entire vessel, radiographic examination is not required of Category B and C butt welds in nozzles and communicating chambers that exceed neither NPS 10 (DN 250) nor 1 1/8 in. (29 mm) wall thickness.

(c) Rules for no radiographic examination of welded joints are specified in Paragraph UW-11*(c)*. Except as required in Paragraph UW-11*(a)*, no radiographic examination of welded joints is required when the pressure vessel or pressure vessel part is designed for external pressure only, or when the joint design complies with requirements specified in Paragraph UW-12*(c)*. Butt joints subjected to no radiography have lower joint design efficiencies compared to butt joints subjected to full or spot radiography.

(d) Rules in Paragraph UW-11*(d)* state that electrogas welds in ferritic materials with any single pass greater than 1 1/2 in. (38 mm) and electroslag welds in ferritic materials shall be ultrasonically examined throughout their entire length in accordance with the requirements of Mandatory Appendix 12 – Ultrasonic Examination of Welds (UT). This ultrasonic examination shall be done following the grain refining (austenitizing) heat treatment or postweld heat treatment.

(e) Rules in Paragraph UW-11*(e)* state that in addition to the requirements in *(a)* and *(b)* above, all welds made by the electron beam or laser beam process shall be ultrasonically examined for their entire length in accordance with the requirements of Mandatory Appendix 12 – Ultrasonic Examination of Welds (UT). Ultrasonic examination may be waived if the following conditions are met:

(1) The nominal thickness at the welded joint does not exceed 1/4 in. (6 mm).

(2) For ferromagnetic materials, the welds are either examined by the magnetic particle examination technique in accordance with Mandatory Appendix 6 – Methods for Magnetic

Particle Examination (MT) or examined by the liquid penetrant examination technique in accordance with Mandatory Appendix 8 – Methods for Liquid Penetrant Examination (PT).

(3) For nonferromagnetic materials, the welds are examined by the liquid penetrant examination technique in accordance with Mandatory Appendix 8.

(f) According to rule specified in Paragraph UW-11*(f)*, when radiography is required for a welded joint in accordance with *(a)* and *(b)* above, and the weld is made by the inertia and continuous drive friction welding processes, the welded joints shall also be ultrasonically examined for their entire length in accordance with Mandatory Appendix 12 – Ultrasonic Examination of Welds (UT).

Rule specified in Paragraph UG-103 – Nondestructive Testing in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC state that where magnetic particle examination is prescribed in Section VIII, Division 1 it must be performed in accordance with Mandatory Appendix 6 – Methods for Magnetic Particle Examination (MT). Where liquid penetrant examination is prescribed in this Division it must be performed in accordance with Mandatory Appendix 8 – Methods for Liquid Penetrant Examination (PT).

Rules specified in Paragraph UW-54 – Qualification of Nondestructive Examination Personnel in the 2021 edition of Section VIII, Division 1 of the ASME BPVC state that personnel performing nondestructive examinations in accordance with UW-51 – Radiographic Examination of Welded Joints, UW-52 – Spot Examination of Welded Joints, or UW-53 – Ultrasonic Examination of Welded Joints shall be qualified and certified in accordance with the requirements of Section V, Article 1 – General Requirements, T-120*(e)*, T-120*(f)*, T-120*(g)*, T-120*(i)*, T-120*(j)*, or T-120*(k)*, as applicable. As discussed in Sect. 6.3.1 of this report, rules specified in Section V, Article 1 – General Requirements, T-120*(e)* in the 2021 edition of Section VIII, Division 1 of the ASME BPVC reference the 2016 edition of SNT-TC-1A and CP-189. Corresponding rules specified in Paragraph UW-51 – Radiographic Examination of Welded Joints, Paragraph UW-52 – Spot Examination of Welded Joints, and Mandatory Appendix 12 – Ultrasonic Examination of Welds (UT), Paragraph 12-2 – Certification of Competence of Nondestructive Examiner in the 2007 edition of Section VIII, Division 1 of the ASME BPVC reference the 2001 edition of SNT-TC-1A and CP-189.

Qualifications for nondestructive examination personnel to perform magnetic particle examinations and liquid penetrant examinations are provided in Mandatory Appendix 6 – Methods for Magnetic Particle Examination (MT), Paragraph 6-2 – Certification of Competency of Nondestructive Examination Personnel and Mandatory Appendix 8 – Methods for Liquid Penetrant Examination (PT), Paragraph 8-2 – Certification of Competency of Nondestructive Examination Personnel, respectively, in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. However, neither of these Mandatory Appendices in the 2007 or the 2021 editions required certification of nondestructive examination personnel to perform magnetic particle examinations and liquid penetrant examinations in accordance with Section V, Article 1 – General Requirements, T-120*(e)* as discussed in Sect. 6.3.1 of this report.

Rules for visual examination of pressure vessels constructed of ferrous and nonferrous materials are not specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. However, Paragraph UIG-96 – Qualification of Visual Examination Personnel in the 2021 edition of Section VIII, Division 1 of the ASME BPVC provides qualification requirements for personnel who perform visual examinations of pressure vessels constructed of impregnated graphite. These rules state that the methods used to qualify and certify personnel must be in accordance with a program established by the employer of the personnel being certified, which are based on the minimum requirements provided in UIG-96*(a)* through *(e)*. Corresponding requirements for qualification of visual examination personnel are not provided in the 2007 edition of Section VIII, Division 1 of the ASME BPVC.

Rules specified in Mandatory Appendix 42 – Diffusion Welding of Microchannel Heat Exchangers in the 2021 edition of Section VIII, Division 1 require that visual examinations shall be performed in accordance with Section V, Article 9. Mandatory Appendix 42 is not included in the 2007 edition of Section VIII, Division 1 of the ASME BPVC.

6.2.2.1 Radiographic Examination Requirements in Section VIII, Division 1

Rules for radiographic examination of welded joints are specified in Paragraph UW-51 – Radiographic Examination of Welded Joints in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. These rules state that all welds that require radiographic examination must be examined in accordance with rules specified in Article 2 – Radiographic Examination, Section V of the ASME BPVC, except as specified Paragraphs UW-51*(a)(1)* through *(a)(4).* Paragraphs UW-51*(b)(1)* through *(b)(4)* define the conditions under which indications shown on the radiographs of welds and characterized as imperfections are unacceptable and must be repaired and the repair radiographed. Acceptance standards for full radiographic examinations are compared in Sect. 6.2.4.2 of this report.

Rules for spot radiographic examination of butt-welded joints are specified in Paragraph UW-52 – Spot Examination of Welded Joints in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. Paragraph UW-52*(c)* states that the minimum length of a spot radiograph is 6 in. (150 mm). Requirements for the minimum extent of spot radiographic examinations are provided in Paragraph UW-52*(b)*. Acceptance standards for spot radiographic examinations are compared in Sect. 6.2.4.2 of this report.

6.2.2.2 Ultrasonic Examination Requirements in Section VIII, Division 1

Rules for ultrasonic examination of welded joints are specific in Paragraph UW-53 – Ultrasonic Examination of Welded Joints in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. According to these rules, ultrasonic examination of welded joints when required or permitted by other paragraphs of this Division must be performed and evaluated to the acceptance standards in accordance with Mandatory Appendix 12 – Ultrasonic Examination of Welds (UT) in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC, as applicable. Paragraph 12-1*(b)* in Mandatory Appendix 12 states that Section V, Article 4 shall be applied for detail requirements in methods and procedures, unless otherwise specified in this Appendix.

Rules specified in Paragraph UW-51*(a)(4)* in the 2021 edition of Section VIII, Division 1 of the ASME BPVC state:

> *As an alternative to the radiographic examination requirements above, all welds in which the thinner of the members joined is 1/4 in. (6 mm) thick and greater may be examined using the ultrasonic (UT) method specified by UW-53(b).*

Paragraph UW-53*(b)* states that ultrasonic examination of welds per UW-51*(a)(4)* shall be performed and evaluated in accordance with the requirements of Section VIII, Division 2, Paragraph 7.5.5. Acceptance standards for ultrasonic examinations and flaw evaluation specified in Section VIII, Division 2, Paragraph 7.5.5 are discussed in Sect. 6.2.4.2 of this report.

6.2.2.3 Magnetic Particle Examination Requirements in Section VIII, Division 1

Paragraph UG-103 – Nondestructive Testing in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC states that where magnetic particle examination is prescribed in this Division it shall be done in accordance with Mandatory Appendix 6 – Methods for Magnetic Particle Examination (MT). The rules for magnetic particle examination specified in Mandatory Appendix 6 state that Section V, Article 7 shall be applied for the detail requirements in methods and procedures, and the additional requirements specified within this Appendix.

These rules describe methods which must be employed whenever magnetic particle examination is specified in this Division. Magnetic particle examination must be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of T-150 of Section V of the ASME BPVC. Acceptance standards for magnetic particle examinations are compared in Sect. 6.2.4.2 of this report of this report.

6.2.2.4 Liquid Penetrant Examination Requirements in Section VIII, Division 1

Paragraph UG-103 – Nondestructive Testing in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC states that where liquid penetrant examination is prescribed in this Division it shall be done in accordance with where liquid penetrant examination is prescribed in this Division it shall be done in accordance with Appendix 8 – Methods for Liquid Penetrant Examination (PT). The rules for liquid penetrant examination specified in Mandatory Appendix 8 state that Section V, Article 6 shall be applied for the detail requirements in methods and procedures, and the additional requirements specified within this Appendix.

These rules describe methods which must be employed whenever liquid penetrant examination is specified in this Division. Liquid penetrant examination must be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of T-150 of Section V of the ASME BPVC. Acceptance standards for liquid penetrant examinations are compared in Sect. 6.2.4.2 of this report of this report.

6.2.2.5 Visual Examination Requirements in Section VIII, Division 1

Rules for visual examination of pressure vessels constructed of ferrous and nonferrous materials are not specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. However, rules for visual examination of pressure vessels constructed of impregnated graphite are specified in Paragraph UIG-95 – Visual Examination in the 2021 edition of Section VIII, Division 1 of the ASME BPVC. These rules state:

> *(a) Parts, material, finished joints, and completed vessels shall be visually examined by the Manufacturer over the full surface to detect defects. Surfaces that are accessible for visual examination after the vessel is completed need not be examined before completion of the vessel or vessel parts; however, such examination shall occur prior to the final pressure test.*
>
> *(b) The Manufacturer shall prepare and qualify a written procedure that meets the requirements of Section V, Article 9 (Visual Examination). The procedure qualification shall be subject to and demonstrated to the Authorized Inspector.*
>
> *(c) The Manufacturer shall designate qualified personnel for Visual Examination.*
>
> *(d) All cemented nozzles must be examined to ensure that cement has flowed around the entire perimeter and that full penetration through the depth of the joint has been achieved.*

Corresponding rules for visual examination of impregnated graphite pressure vessels are not specified in the 2007 edition of Section VIII, Division 1 of the ASME BPVC.

Rules specified in Mandatory Appendix 42 – Diffusion Welding of Microchannel Heat Exchangers in the 2021 edition of Section VIII, Division 1 require that visual examinations shall be performed in accordance with Section V, Article 9. Mandatory Appendix 42 is not included in the 2007 edition of Section VIII, Division 1 of the ASME BPVC.

6.2.3 General NDE Requirements in Section VIII, Division 2

Inspection and examination requirements are provided in Part 7 – Inspection and Examination Requirements in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. Rules in Paragraph 7.4 – Nondestructive Examination Requirements for examination of welded joints state:

7.4.1.1 All finished welds shall be subject to visual examination in accordance with 7.5.2.

7.4.1.2 All finished welds shall be subject to nondestructive examination depending on Examination Group selected in 7.4.2 and the Joint Category and Weld Type as defined in 4.2.

7.4.1.3 All welding shall be subject to in-process examination by visual examination at the fit-up stage and during back gouging.

Part 7, Table 7.1 – Examination Groups for Pressure Vessels defines the Examination Groups assigned to welded joints based on the manufacturing complexity of the material group, the maximum thickness, the welding process, and the selected joint efficiency. The extents of examination given in Table 7.2 – Nondestructive Examinations are percentage (e.g., 10%, 25%, or 100%, as applicable) of the total lengths of the welded joints under consideration.

Rules specified in Part 7, Paragraph 7.4.4 – Selection of Examination Method for Internal (Volumetric) Flaws state:

> *The selection of the examination method for internal flaws (radiographic or ultrasonic) shall be in accordance with Table 7.3. The basis of the selection is the most suitable method to the relevant application in relation to the material type and thickness, as well as any additional NDE requirements specified in the User's Design Specification [see 2.2.3.2(a)].*

According to requirements provided in Table 7.3 – Selection of Nondestructive Testing Method for Full Penetration Joints in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC, full penetration joints with a thickness less than 1/2 in. must be examined using radiographic examination, but full penetration joints with a thickness equal to or greater than 1/2 in. may be examined using either radiographic or ultrasonic examination.

Rules specified in Part 7, Paragraph 7.4.5 – Selection of Examination Method for Surface Flaws state:

> *For nonferromagnetic or partially magnetic materials, or magnetic materials welded with nonferromagnetic or partially ferromagnetic filler metals, Liquid Penetrant Examination in accordance with 7.5.7 shall be used. For magnetic steels, Magnetic Particle Examination or Liquid Penetrant Examination, in accordance with 7.5.6 and 7.5.7 respectively, shall be used as applicable.*

Paragraph 7.3 – Qualification of Nondestructive Examination Personnel in the 2021 edition of Section VIII, Division 2 of the ASME BPVC states that personnel performing nondestructive examinations in accordance with:

Paragraph 7.5.3 – Radiographic Examination (RT)

Paragraph 7.5.4 – Ultrasonic Examination (UT)

Paragraph 7.5.5 – Ultrasonic Examination Used In lieu of Radiographic Examination

Paragraph 7.5.6 – Magnetic Particle Examination (MT)

Paragraph 7.5.7 – Liquid Penetrant Examination (PT)

Paragraph 7.5.8 – Eddy Current Surface Examination Procedure Requirements (ET) shall be qualified and certified in accordance with the requirements of Section V, Article 1 – General Requirements, T-120*(e)*, T-120*(f),* T-120*(g)*, T-120*(i)*, T-120*(j)*, or T-120*(k)*, as applicable. Differences in requirements provided in Section V, Article 1 – General Requirements, Paragraph T-120 in the 2007 and 2021 editions concerning qualification of NDE personnel are discussed in Sect. 6.3.1 of this report.

6.2.3.1 Radiographic Examination Requirements in Section VIII, Division 2

Rules for radiographic examination of joints in pressure vessels fabricated by welding in accordance with requirements specified in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC are provided in Part 7 – Inspection and Examination Requirements, Paragraph 7.5.3 – Radiographic Examination.

Paragraph 7.5.3.1 – Examination Method in 2021 edition of Section VIII, Division 2 of the ASME BPVC states that all welded joints to be radiographed shall be examined and documented in accordance with Section V, Article 2 except as specified below.

(a) A complete set of radiographs and records, as described in Section V, Article 2, T-291 and T-292, for each vessel or vessel part shall be retained by the Manufacturer in accordance with 2.3.5.

(b) Personnel performing and evaluating radiographic examinations required by this Division shall be qualified and certified in accordance with 7.3.

(c) Evaluation of radiographs shall only be performed by RT Level II or III personnel.

(d) Demonstration of density and Image Quality Indicator (IQI) image requirements on production or technique radiographs shall be considered satisfactory evidence of compliance with Section V, Article 2.

(e) Final acceptance of radiographs shall be based on the ability to see the prescribed hole (IQI) image and the specified hole or the designated wire of a wire IQI.

(f) Ultrasonic examination of SAW welds in 2-1/4 Cr–1Mo–1/4 V vessels in accordance with 7.5.4.1*(e)* is required.

Requirements in Paragraph 7.5.3.1*(b)* in the 2007 edition of Section VIII, Division 2 of the ASME BPVC state that the Manufacturer shall certify that personnel performing and evaluating radiographic examinations required by this Division have been qualified and certified in accordance with their employer's written practice. SNT-TC-1A (2001 edition) shall be used as a guideline for employers to establish their written practice for qualification and certification of their personnel. Alternatively, the ASNT Central Certification Program (ACCP) or CP-189 may be used to fulfill the examination and demonstration requirements of SNT-TC-1A and the employer's written practice. Provisions for training, experience, qualification, and certification of NDE personnel; shall be described in the Manufacturer's Quality Control System Manual. Evaluation of radiographic examination shall only be performed by RT Level II or III personnel.

Requirements in Paragraph 7.5.3.1*(b)* in the 2021 edition of Section VIII, Division 2 of the ASME BPVC state that personnel performing and evaluating radiographic examinations required by this Division shall be qualified and certified in accordance with Paragraph 7.3 – Qualification of Nondestructive Examination Personnel. Paragraph 7.3 states that personnel performing nondestructive examinations in accordance with 7.5.3, 7.5.4, 7.5.5, 7.5.6, 7.5.7, or 7.5.8 shall be qualified and certified in accordance with the requirements of Section V, Article 1 – General Requirements, T-120*(e)*, T-120*(f),* T-120*(g)*, T-120*(i)*, T-120*(j)*, or T-120*(k)*, as applicable, as discussed in Sect. 6.3.1 of this report. Note that T-120*(e)* in Section V, Article 1 require compliance with the either SNT-TC-1A (2016 Edition) or ANSI/ASNT

CP-189 (2016 Edition). Requirements in Paragraph 7.5.3.1*(c)* further state that evaluation of radiographic examination shall only be performed by RT Level II or III personnel.

6.2.3.2 Ultrasonic Examination Requirements in Section VIII, Division 2

Rules for ultrasonic examination of joints in pressure vessels fabricated by welding in accordance with requirements specified in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC are provided in Part 7 – Inspection and Examination Requirements, Paragraph 7.5.4 – Ultrasonic Examination. According to these rules in the 2021 edition, all welded joints subjected to ultrasonic examination must be examined in accordance with requirements specified in Section V, Article 4 except as specified in Paragraph 7.5.4.1*(a)* through *(e)*.

- *(a)* A complete set of records, as described in Section V, Article 4, T-491 and T-492, for each vessel or vessel part shall be retained by the Manufacturer in accordance with 2-C.3. In addition, a record of repaired areas shall be noted as well as the results of the reexamination of the repaired areas. The Manufacturer shall also maintain a record from uncorrected areas having responses that exceed 50% of the reference level. This record shall locate each area, the response level, the dimensions, the depth below the surface, and the classification.
- *(b)* Personnel performing and evaluating ultrasonic examinations required by this Division shall be qualified and certified in accordance with 7.3.
- *(c)* Flaw evaluations shall only be performed by UT Level II or III personnel.
- *(d)* Ultrasonic examination shall be performed in accordance with a written procedure certified by the Manufacturer to be in accordance with the requirements of Section V, Article 1, T-150.
- *(e)* SAW welds in 2-1/4Cr–1Mo–1/4V vessels require ultrasonic examination using specialized techniques beyond those required by this Division (see 2.2.3.2). Annex A of API Recommended Practice 934-A may be used as a guide in the selection of the examination specifics.

Requirements in Paragraph 7.5.4.1*(b)* in the 2007 edition of Section VIII, Division 2 of the ASME BPVC state that the Manufacturer shall certify that personnel performing and evaluating ultrasonic examinations required by this Division have been qualified and certified in accordance with their employer's written practice. SNT-TC-1A (2001 edition) shall be used as a guideline for employers to establish their written practice for qualification and certification of their personnel. Alternatively, the ASNT Central Certification Program (ACCP) or CP-189 (2001 edition) may be used to fulfill the examination and demonstration requirements of SNT-TC-1A and the employer's written practice. Provisions for training, experience, qualification, and certification of NDE personnel; shall be described in the Manufacturer's Quality Control System Manual. Evaluation of ultrasonic examination shall only be performed by UT Level II or III personnel.

Requirements in Paragraph 7.5.4.1*(b)* in the 2021 edition of Section VIII, Division 2 of the ASME BPVC state that personnel performing and evaluating ultrasonic examinations required by this Division shall be qualified and certified in accordance with Paragraph 7.3 – Qualification of Nondestructive Examination Personnel. Evaluation of ultrasonic examination shall only be performed by UT Level II or III personnel. Paragraph 7.3 states that personnel performing nondestructive examinations be qualified and certified in accordance with the requirements of Section V, Article 1 – General Requirements, T-120*(e)*, T-120*(f)*, T-120*(g)*, T-120*(i)*, T-120*(j)*, or T-120*(k)*, as applicable, as discussed in Sect. 6.3.1 of this report. Note that T-120*(e)* in Section V, Article 1 require compliance with the either SNT-TC-1A (2016 Edition) or ANSI/ASNT CP-189 (2016 Edition).

Rules specified in Part 7, Paragraph 7.5.5 Ultrasonic Examination Used in Lieu of Radiographic Examination in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC, when used in lieu of the radiographic examination requirements of 7.5.3, automated or semi-automated ultrasonic shall be performed in accordance with a written procedure conforming to the requirements of Section V, Article 4, Mandatory Appendix VIII – Ultrasonic Examination Requirements for Fracture-Mechanics-Based Acceptance Criteria or Mandatory Appendix XI – Full Matrix Capture, as applicable, and the additional requirements specified in Paragraph 7.5.5.1*(a)* through *(f)*.

Requirements in Paragraph 7.5.5.1*(g)* in the 2007 edition of Section VIII, Division 2 of the ASME BPVC state that personnel performing and evaluating UT examinations shall be qualified and certified in accordance with their employer's written practice. ASNT SNT-TC-1A (2001 edition) or CP-189 (2001 edition) shall be used as a guideline. Only UT Level II or III personnel shall analyze the data or interpret the results.

Requirements in Paragraph 7.5.5.1*(c)* in the 2021 edition of Section VIII, Division 2 of the ASME BPVC state that personnel performing and evaluating UT examinations shall be qualified and certified in accordance with 7.3. Only UT Level II or Level III personnel shall analyze the data or interpret the results. In addition, UT personnel shall meet the requirements of Section V, Article 4, Mandatory Appendix VIII – Ultrasonic Examination Requirements for Fracture-Mechanics-Based Acceptance Criteria, VIII-423 prior to performing production scans. Paragraph 7.3 states that personnel performing nondestructive examinations be qualified and certified in accordance with the requirements of Section V, Article 1 – General Requirements, T-120*(e)*, T-120*(f),* T-120*(g)*, T-120*(i)*, T-120*(j)*, or T-120*(k)*, as applicable, as discussed in Sect. 6.3.1 of this report. Note that T-120*(e)* in Section V, Article 1 require compliance with the either SNT-TC-1A (2016 Edition) or ANSI/ASNT CP-189 (2016 Edition).

6.2.3.3 Magnetic Particle Examination Requirements in Section VIII, Division 2

Rules for magnetic particle examination of welded joints in pressure vessels fabricated by welding in accordance with requirements specified in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC are provided in Part 7 – Inspection and Examination Requirements, Paragraph 7.5.6 – Magnetic Particle Examination (MT). According to these rules in the 2021 edition, all magnetic particle examinations shall be performed and documented in accordance with Section V, Article 7 except as specified in Paragraph 7.5.6.1 below:

- *(a)* A complete set of records, as described in Section V, Article 7, T-790, for each vessel or vessel part shall be retained by the Manufacturer until the Manufacturer's Data Report has been signed by the Inspector.
- *(b)* Personnel performing and evaluating magnetic particle examinations required by this Division shall be qualified and certified in accordance with 7.3. Evaluation of magnetic particle examination shall only be performed by MT Level II or III personnel.
- *(c)* Magnetic particle examination shall be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of Section V, Article 1, T-150.
- *(d)* Indications will be revealed by retention of magnetic particles. All such indications are not necessarily imperfections, however, since excessive surface roughness, magnetic permeability variations (such as the edge of heat-affected zones), etc., may produce similar indications. An indication of an imperfection may be larger than the imperfection that causes it; however, the size of the indication is the basis for acceptance evaluation. Only indications which have any dimension greater than 1.5 mm (1/16 in.) shall be considered relevant.
  - *(1)* A linear indication is one having a length greater than three times the width.
  - *(2)* A rounded indication is one of circular or elliptical shape with a length equal to or less than three times its width.
  - *(3)* Any questionable or doubtful indications shall be reexamined to determine whether or not they are relevant.

Requirements in Paragraph 7.5.6.1*(b)* in the 2007 edition of Section VIII, Division 2 of the ASME BPVC state that the Manufacturer shall certify that personnel performing and evaluating magnetic particle examinations required by this Division have been qualified and certified in accordance with their employer's written practice. SNT-TC-1A (2001 edition) shall be used as a guideline for employers to establish their written practice for qualification and certification of their personnel. Alternatively, the ASNT Central Certification Program (ACCP) or CP-189 (2001 edition) may be used to fulfill the examination and demonstration requirements of SNT-TC-1A and the employer's written practice. Provisions for training, experience, qualification, and certification of NDE personnel; shall be described in the Manufacturer's Quality Control System Manual. Evaluation of magnetic particle examination shall only be performed by MT Level II or III personnel.

Requirements in Paragraph 7.5.6.1*(b)* in the 2021 edition of Section VIII, Division 2 of the ASME BPVC state that personnel performing and evaluating magnetic particle examinations required by this Division shall be qualified and certified in accordance with Paragraph 7.3 – Qualification of Nondestructive Examination Personnel. Evaluation of magnetic particle penetrant examination shall only be performed by MT Level II or III personnel. Paragraph 7.3 states that personnel performing nondestructive examinations be qualified and certified in accordance with the requirements of Section V, Article 1 – General Requirements, T-120*(e)*, T-120*(f),* T-120*(g)*, T-120*(i)*, T-120*(j)*, or T-120*(k)*, as applicable, as discussed in Sect. 6.3.1 of this report. Note that T-120*(e)* in Section V, Article 1 require compliance with the either SNT-TC-1A (2016 Edition) or ANSI/ASNT CP-189 (2016 Edition).

6.2.3.4 Liquid Penetrant Examination Requirements in Section VIII, Division 2

Rules for liquid penetrant examination of welded joints in pressure vessels fabricated by welding in accordance with requirements specified in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC are provided in Part 7 – Inspection and Examination Requirements, Paragraph 7.5.7 – Liquid Penetrant Examination (PT). According to these rules in the 2021 edition, all liquid penetrant examinations shall be performed and documented in accordance with Section V, Article 6 except as specified in Paragraph 7.5.7.1 below:

(a) A complete set of records, as described in Section V, Article 6, T-691 and T-692, for each vessel or vessel part shall be retained by the Manufacturer until the Manufacturer's Data Report has been signed by the Inspector.

(b) Personnel performing and evaluating liquid penetrant examinations required by this Division shall be qualified and certified in accordance with 7.3. Evaluation of liquid penetrant examination shall only be performed by PT Level II or III personnel.

(c) Liquid penetrant examination shall be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of Section V, Article 1, T-150.

(d) An indication of an imperfection may be larger than the imperfection that causes it; however, the size of the indication is the basis for acceptance evaluation. Only indications with major dimensions greater than 1.5 mm (1/16 in.) shall be considered relevant.

  (1) A linear indication is one having a length greater than three times the width.

  (2) A rounded indication is one of circular or elliptical shape with a length equal to or less than three times its width.

  (3) Any questionable or doubtful indications shall be reexamined to determine whether or not they are relevant.

Requirements in Paragraph 7.5.7.1*(b)* in the 2007 edition of Section VIII, Division 2 of the ASME BPVC state that the Manufacturer shall certify that personnel performing and evaluating liquid penetrant examinations required by this Division have been qualified and certified in accordance with their employer's written practice. SNT-TC-1A (2001 edition) shall be used as a guideline for employers to establish their written practice for qualification and certification of their personnel. Alternatively, the ASNT Central Certification Program (ACCP) or CP-189 (2001 edition) may be used to fulfill the examination and demonstration requirements of SNT-TC-1A and the employer's written practice. Provisions for training, experience, qualification, and certification of NDE personnel; shall be described in the Manufacturer's Quality Control System Manual. Evaluation of liquid penetrant examination shall only be performed by PT Level II or III personnel.

Requirements in Paragraph 7.5.7.1*(b)* in the 2021 edition of Section VIII, Division 2 of the ASME BPVC state that personnel performing and evaluating liquid penetrant examinations required by this Division shall be qualified and certified in accordance with Paragraph 7.3 – Qualification of Nondestructive Examination Personnel. Evaluation of liquid penetrant examination shall only be performed by PT Level II or III personnel. Paragraph 7.3 states that personnel performing nondestructive examinations be qualified and certified in accordance with the requirements of Section V, Article 1 – General Requirements, T-120*(e)*, T-120*(f),* T-120*(g)*, T-120*(i)*, T-120*(j)*, or T-120*(k)*, as applicable, as discussed in Sect. 6.3.1 of this report. Note that T-120*(e)* in Section V, Article 1 require compliance with the either SNT-TC-1A (2016 Edition) or ANSI/ASNT CP-189 (2016 Edition).

6.2.3.5 Eddy Current Examination Requirements in Section VIII, Division 2

Rules for eddy current surface examination procedure requirements are specified in Part 7 – Inspection and Examination Requirements, Paragraph 7.5.8 – Eddy Current Surface Examination Procedure Requirements (ET) in the 2007 and 2021 editions of Section VIII, Section VIII, Division 2 of the ASME BPVC. According to these rules in the 2021 edition, all eddy current examinations shall be performed and documented as described in Paragraph 7.5.7.1 below:

(a) A complete set of records for each vessel or vessel part shall be retained by the Manufacturer until the Manufacturer's Data Report has been signed by the Inspector.
(b) Personnel performing and evaluating eddy current examinations required by this Division shall be qualified and certified in accordance with 7.3. Evaluation of eddy current examination shall only be performed by ET Level II or III personnel.
(c) Eddy current examinations shall be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of Section V, Article 1, T-150.

Requirements in Paragraph 7.5.8.1*(b)* in the 2007 edition of Section VIII, Division 2 of the ASME BPVC state that the Manufacturer shall certify that personnel performing and evaluating eddy current examinations required by this Division have been qualified and certified in accordance with their employer's written practice. SNT-TC-1A (2001 edition) shall be used as a guideline for employers to establish their written practice for qualification and certification of their personnel. Alternatively, the ASNT Central Certification Program (ACCP) or CP-189 (2001 edition) may be used to fulfill the examination and demonstration requirements of SNT-TC-1A and the employer's written practice. Provisions for training, experience, qualification, and certification of NDE personnel; shall be described in the Manufacturer's Quality Control System Manual. Evaluation of eddy current examination shall only be performed by ET Level II or III personnel.

Requirements in Paragraph 7.5.8.1*(b)* in the 2021 edition of Section VIII, Division 2 of the ASME BPVC state that personnel performing and evaluating eddy current examinations required by this Division shall be qualified and certified in accordance with Paragraph 7.3 – Qualification of Nondestructive Examination Personnel. Evaluation of eddy current examination shall only be performed by ET Level II or III personnel. Paragraph 7.3 states that personnel performing nondestructive examinations be qualified and certified in accordance with the requirements of Section V, Article 1 – General Requirements, T-120*(e)*, T-120*(f),* T-120*(g)*, T-120*(i)*, T-120*(j)*, or T-120*(k)*, as applicable, as discussed in Sect. 6.3.1 of this report. Note that T-120*(e)* in Section V, Article 1 require compliance with the either SNT-TC-1A (2016 Edition) or ANSI/ASNT CP-189 (2016 Edition).

6.2.3.6 Visual Examination Requirements in Section VIII, Division 2

Rules for visual examination of joints in pressure vessels fabricated by welding in accordance with requirements specified in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC are specified in Part 7 – Inspection and Examination Requirements, Paragraph 7.5.2 – Visual Examination.

According to rules in the Paragraph 7.5.2.1 – Examination Method in the 2021 edition, all accessible welds for pressure-retaining parts shall be visually examined. Personnel performing visual examinations shall have vision, with correction if necessary, to read a Jaeger Type No. 2 Standard Chart at a distance of not less than 300 mm (12 in.) and be capable of distinguishing and differentiating contrast between colors used. Compliance with this requirement shall be demonstrated annually.

In comparison, requirements in Paragraph 7.5.2.1 – Examination Method in the 2007 edition state that all welds for pressure retaining parts shall be visually examined. Personnel performing visual examinations shall pass the annual eye test in accordance with paragraph 7.A.2.2. Paragraph 7.A.2.2*(b)(1)* – Inspection and Examination Duties states that the examiner has vision, with correction if necessary, to read a Jaeger Type No. 2 Standard Chart, at a distance of not less than 300 mm (12 in.) and is capable of distinguishing and differentiating contrast between colors used. Compliance with these requirements shall be demonstrated annually.

6.2.4 Acceptance Standards

Specified NDE acceptance standards in the 2021 editions of Section I; Section VIII, Division 1; and Section VIII, Division 2 remain essentially the same as the specified NDE acceptance standards in the 2007 editions of Section I; Section VIII, Division 1; and Section VIII, Division 2 of the ASME BPVC. A side-by-side comparison of acceptance standards for radiographic, ultrasonic, magnetic particle, liquid penetrant, and eddy current examinations is provided in Tables 6.1 through 6.5 of this report.

Table 6.1 Radiographic examination acceptance standards in the 2007 and 2021 editions of Section I of the ASME BPVC

Radiographic Examination	
Section I – 2007 Edition	**Section I – 2021 Edition**
Part PW – Requirements for Boilers Fabricated by Welding	**Part PW – Requirements for Boilers Fabricated by Welding**
PW-51 Radiographic Examination	**PW-51 Radiographic Examination**
PW-51.3 Indications shown on the radiographs of welds and characterized as imperfections are unacceptable under the following conditions, and shall be repaired as provided in PW-40 and the repair radiographed to PW-51:	**PW-51.3** Indications shown on the radiographs of welds and characterized as imperfections are unacceptable under the following conditions, and shall be repaired as provided in PW-40 and the repair radiographed to PW-51:
PW-51.3.1 Any indication characterized as a crack, or zone of incomplete fusion or penetration.	**PW-51.3.1** Any indication characterized as a crack, or zone of incomplete fusion or penetration.

Radiographic Examination	
PW-51.3.2 Any other elongated indication on the radiograph that has a length greater than: *(a)* 1/4 in. (6 mm) for t up to 3/4 in. (19 mm) *(b)* 1/3t for t from 3/4 in. (19 mm) to 2 1/4 in. (57 mm) *(c)* 3/4 in. (19 mm) for t over 2 1/4 in. (57 mm) where t is the thickness of the weld.	**PW-51.3.2** Any other elongated indication on the radiograph that has a length greater than: *(a)* 1/4 in. (6 mm) for t up to 3/4 in. (19 mm) *(b)* 1/3t for t from 3/4 in. (19 mm) to 2 1/4 in. (57 mm) *(c)* 3/4 in. (19 mm) for t over 2 1/4 in. (57 mm) where t is the thickness of the weld.
PW-51.3.3 Any group of aligned indications that have an aggregate length greater than t in a length of $12t$, except when the distance between the successive imperfections exceeds $6L$ where L is the length of the longest imperfection in the group.	**PW-51.3.3** Any group of aligned indications that have an aggregate length greater than t in a length of $12t$, except when the distance between the successive imperfections exceeds $6L$ where L is the length of the longest imperfection in the group.
PW-51.3.4 Rounded indications in excess of those shown in A-250.	**PW-51.3.4** Rounded indications in excess of those shown in A-250.
A-250 Acceptance Standards for Radiographically Determined Rounded Indications in Welds	**A-250 Acceptance Standards for Radiographically Determined Rounded Indications in Welds**
A-250.3 Acceptance Criteria	**A-250.3 Acceptance Criteria**
A-250.3.2 Relevant Indications (See Table A-250.3.2 for Examples). Only those rounded indications which exceed the following dimensions shall be considered relevant: *(a)* 1/10t for *t* less than 1/8 in. (3 mm) *(b)* 1/64 in. (0.4 mm) for *t* 1/8 in. to 1/4 in. (6 mm), inclusive *(c)* 1/32 in. (0.8 mm) for t 1/4 in. (6 mm) to 2 in. (50 mm), inclusive *(d)* 1/16 in. (1.6 mm) for t greater than 2 in. (50 mm)	**A-250.3.2 Relevant Indications (See Table A-250.3.2 for Examples).** Only those rounded indications which exceed the following dimensions shall be considered relevant: *(a)* 1/10t for *t* less than 1/8 in. (3 mm) *(b)* 1/64 in. (0.4 mm) for *t* 1/8 in. to 1/4 in. (6 mm), inclusive *(c)* 1/32 in. (0.8 mm) for t 1/4 in. (6 mm) to 2 in. (50 mm), inclusive *(d)* 1/16 in. (1.6 mm) for t greater than 2 in. (50 mm)
A-250.3.3 Maximum Size of Rounded Indication (See Table A-250.3.2 for Examples). The maximum permissible size of any indication shall be 1/4t, or 5/32 in. (4 mm), whichever is smaller; except that an isolated indication separated from an adjacent indication by 1 in. (25 mm) or more may be 1/3t, or 1/4 in. (6 mm), whichever is less. For t greater than 2 in. (50 mm) the maximum permissible size of an isolated indication shall be increased to 3/8 in. (10 mm).	**A-250.3.3 Maximum Size of Rounded Indication (See Table A-250.3.2 for Examples).** The maximum permissible size of any indication shall be 1/4t, or 5/32 in. (4 mm), whichever is smaller; except that an isolated indication separated from an adjacent indication by 1 in. (25 mm) or more may be 1/3t, or 1/4 in. (6 mm), whichever is less. For t greater than 2 in. (50 mm) the maximum permissible size of an isolated indication shall be increased to 3/8 in. (10 mm).
A-250.3.4 Aligned Rounded Indications. Aligned rounded indications are acceptable when the summation of the diameters of the indications is less than t in a length of $12t$ (See Figure A-250.3.4-1). The length of groups of aligned rounded indications and the spacing between the groups shall meet the requirements of Figure A-250.3.4-2.	**A-250.3.4 Aligned Rounded Indications.** Aligned rounded indications are acceptable when the summation of the diameters of the indications is less than t in a length of $12t$ (See Figure A-250.3.4-1). The length of groups of aligned rounded indications and the spacing between the groups shall meet the requirements of Figure A-250.3.4-2.
A-250.3.5 Spacing. The distance between adjacent rounded indications is not a factor in determining acceptance or rejection, except as required for isolated indications or groups of aligned indications.	**A-250.3.5 Spacing.** The distance between adjacent rounded indications is not a factor in determining acceptance or rejection, except as required for isolated indications or groups of aligned indications.

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A-250.3.6 Rounded Indication Charts. The rounded indications characterized as imperfections shall not exceed that shown in the charts. The charts in Figures A-250.3.6-1 through A-250.3.6-6 illustrate various types of assorted, randomly dispersed, and clustered rounded indications for different weld thicknesses greater than 1/8 in. (3 mm). These charts represent the maximum acceptable concentration limits for rounded indications. The chart for each thickness range represents full-scale 6 in. (150 mm) radiographs and shall not be enlarged or reduced. The distributions shown are not necessarily the patterns that may appear on the radiograph but are typical of the concentration and size of indications permitted.	**A-250.3.6 Rounded Indication Charts.** The rounded indications characterized as imperfections shall not exceed that shown in the charts. The charts in Figures A-250.3.6-1 through A-250.3.6-6 illustrate various types of assorted, randomly dispersed, and clustered rounded indications for different weld thicknesses greater than 1/8 in. (3 mm). These charts represent the maximum acceptable concentration limits for rounded indications. The chart for each thickness range represents full-scale 6 in. (150 mm) radiographs and shall not be enlarged or reduced. The distributions shown are not necessarily the patterns that may appear on the radiograph but are typical of the concentration and size of indications permitted.
A-250.3.7 Weld Thickness *t* Less Than 1/8 in. (3 mm). For *t* less than 1/8 in. (3 mm), the maximum number of rounded indications shall not exceed 12 in a 6 in. (150 mm) length of weld. A proportionally fewer number of indications shall be permitted in welds less than 6 in. (150 mm) in length.	**A-250.3.7 Weld Thickness *t* Less Than 1/8 in. (3 mm).** For *t* less than 1/8 in. (3 mm), the maximum number of rounded indications shall not exceed 12 in a 6 in. (150 mm) length of weld. A proportionally fewer number of indications shall be permitted in welds less than 6 in. (150 mm) in length.
A-250.3.8 Clustered Indications. The illustrations for clustered indications show up to four times as many indications in a local area, as that shown in the illustrations for random indications. The length of an acceptable cluster shall not exceed the lesser of 1 in. (25 mm) or $2t$. Where more than one cluster is present, the sum of the lengths of the clusters shall not exceed 1 in. (25 mm) in a 6 in. (150 mm) length of weld.	**A-250.3.8 Clustered Indications.** The illustrations for clustered indications show up to four times as many indications in a local area, as that shown in the illustrations for random indications. The length of an acceptable cluster shall not exceed the lesser of 1 in. (25 mm) or $2t$. Where more than one cluster is present, the sum of the lengths of the clusters shall not exceed 1 in. (25 mm) in a 6 in. (150 mm) length of weld.

Section VIII, Division 1 – 2007 Edition	Section VIII, Division 1 – 2021 Edition
Part UW – Requirements for Pressure Vessels Fabricated by Welding	**Part UW – Requirements for Pressure Vessels Fabricated by Welding**
UW-51 Full Radiography *(b)(1)* any indication characterized as a crack or zone of incomplete fusion or penetration. *(b)(2)* any other elongated indication on the radiograph which has length greater than: *(a)* 1⁄4 in. (6 mm) for t up to 3⁄4 in. (19 mm) *(b)* 1⁄3t for t from 3⁄4 in. (19 mm) to 21⁄4 in. (57 mm) *(c)* 3⁄4 in. (19 mm) for t over 21⁄4 in. (57 mm) where: t – the thickness of the weld excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t. *(b)(3)* any group of aligned indications that have an aggregate length greater than t in a length of $12t$,	**UW-51 Full Radiography** *(b)(1)* any indication characterized as a crack or zone of incomplete fusion or penetration. *(b)(2)* any other elongated indication on the radiograph which has length greater than: *(-a)* 1/4 in. (6 mm) for t up to 3/4 in. (19 mm) *(-b)* 1/3 t for t from 3/4 in. (19 mm) to 2 1/4 in. (57 mm) *(-c)* 3/4 in. (19 mm) for t over 2 1/4 in. (57 mm) where: t – the thickness of the weld excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t. *(b)(3)* any group of aligned indications that have an aggregate length greater than t in a length of $12t$,

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except when the distance between the successive imperfections exceeds $6L$ where L is the length of the longest imperfection in the group.	except when the distance between the successive imperfections exceeds $6L$ where L is the length of the longest imperfection in the group.
(b)(4) rounded indications in excess of that specified by the acceptance standards given in Appendix 4.	*(b)(4)* rounded indications in excess of that specified by the acceptance standards given in Mandatory Appendix 4.
UW-52 Spot Radiography	**UW-52 Spot Radiography**
(c)(1) Welds in which indications are characterized as cracks or zones of incomplete fusion or penetration shall be unacceptable.	*(c)(1)* Welds in which indications are characterized as cracks or zones of incomplete fusion or penetration shall be unacceptable.
(c)(2) Welds in which indications are characterized as slag inclusions or cavities shall be unacceptable if the length of any such indication is greater than $2⁄3t$ where t is the thickness of the weld excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t. If several indications within the above imitations exist in line, the welds shall be judged acceptable if the sum of the longest dimensions of all such indications is not more than *t* in a length of $6t$ (or proportionately for radiographs shorter than $6t$) and if the longest indications considered are separated by at least $3L$ of acceptable weld metal where L is the length of the longest indication. The maximum length of acceptable indications shall be 3/4 in. (19 mm). Any such indications shorter than 1⁄4 in. (6 mm) shall be acceptable for any plate thickness.	*(c)(2)* Welds having indications characterized as slag inclusions or cavities are unacceptable when the indication length exceeds $2/3t$, where t is defined as shown in UW-51*(b)(2)*. For all thicknesses, indications less than 1/4 in. (6 mm) are acceptable, and indications greater than 3/4 in. (19 mm) are unacceptable. Multiple aligned indications meeting these acceptance criteria are acceptable when the sum of their longest dimensions indications does not exceed *t* within a length of $6t$ (or proportionally for radiographs shorter than $6t$), and when the longest length L for each indication is separated by a distance not less than $3L$ from adjacent indications.
(c)(3) Rounded indications are not a factor in the acceptability of welds not required to be fully radiographed.	*(c)(3)* Rounded indications are not a factor in the acceptability of welds not required to be fully radiographed.

Section VIII, Division 2 – 2007 Edition	Section VIII, Division 2 – 2021 Edition
Part 7 – Inspection and Examination Requirements	**Part 7 – Inspection and Examination Requirements**
Paragraph 7.5.3 Radiographic Examination	**Paragraph 7.5.3 Radiographic Examination**
Paragraph 7.5.3.2 Acceptance Criteria	**Paragraph 7.5.3.2 Acceptance Criteria**
(a) **<u>Linear Indications</u>**	*(a)* **<u>Linear Indications</u>**
(*1*) Terminology	(*1*) Terminology
Thickness t – the thickness of the weld excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the fillet throat shall be included in the calculation of t.	Thickness t – When cited in the acceptance criteria of the various examination methods in 7.5 and Table 7.2, the thickness t is defined as the thickness of the weld, excluding any allowable reinforcement [see 6.2.4.1*(d)*]. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t.
(*2*) Acceptance/Rejection Criteria	(*2*) Acceptance/Rejection Criteria

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i) Any crack or zone of incomplete fusion or lack of penetration	*(-a)* Any crack or zone of incomplete fusion or lack of penetration
ii) Any other linear indication that has a length greater than:	*(-b)* Any other linear indication that has a length greater than:
1. 6 mm (1/4 in) for t less than or equal to 19 mm (3/4 in),	*(-1)* 6 mm (1/4 in.) for t less than or equal to 19 mm (3/4 in.),
2. $t/3$ for t greater than 19 mm (3/4 in) and less than or equal to 57 mm (2 1/4 in),	*(-2)* $t/3$ for t greater than 19 mm (3/4 in.) and less than or equal to 57 mm (2–1/4 in.),
3. 19 mm (3/4 in) for t greater than 57 mm (2 1/4 in).	*(-3)* 19 mm (3/4 in.) for t greater than 57 mm (2-1/4 in.).
	(-c) Any group of indications in line that has an aggregate length greater than t in a length of 12 t except when the distance between the successive imperfections exceeds $6L$, where L is the length of the longest imperfection in the group.
iii) Internal root weld conditions are acceptable when the density or image brightness change as indicated in the radiograph is not abrupt. Linear indications on the radiograph at either edge of such conditions shall be evaluated in accordance with the other sections of this paragraph.	*(-d)* Internal root weld conditions are acceptable when the density or image brightness change as indicated in the radiograph is not abrupt. Linear indications on the radiograph at either edge of such conditions shall be evaluated in accordance with the other sections of this paragraph.
b) **Rounded Indications**	*(b)* **Rounded Indications**
1) Terminology	(*1*) Terminology
i) Rounded Indications – indications with a maximum length of three times the width or less on the radiograph are defined as rounded indications. These indications may be circular, elliptical, conical, or irregular in shape.	*(-a)* Rounded Indications - indications with a maximum length of three times the width or less on the radiograph are defined as rounded indications. These indications may be circular, elliptical, conical, or irregular in shape and may have tails. When evaluating the size of an indication, the tail shall be included.
ii) Aligned Indications – a sequence of four or more rounded indications shall be considered to be aligned when they touch a line parallel to the length of the weld drawn through the center of the two outer rounded indications.	*(-b)* Aligned Indications - a sequence of four or more rounded indications shall be considered to be aligned when they touch a line parallel to the length of the weld drawn through the center of the two outer rounded indications.
iii) Thickness t – the thickness of the weld, excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the fillet throat shall be included in the calculation of t.	*(-c)* Thickness t - When cited in the acceptance criteria of the various examination methods in 7.5 and Table 7.2, the thickness t is defined as the thickness of the weld, excluding any allowable reinforcement [see 6.2.4.1*(d)*]. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t.
2) Acceptance Criteria	*(2)* Acceptance Criteria
i) Rounded Indication Charts – relevant rounded indications characterized as imperfections shall not exceed those shown in Figures 7.5 through 7.10, which illustrate various types of assorted, randomly dispersed, and clustered rounded indications for different weld thicknesses greater than 3 mm (1/8 in). The charts for each thickness range represent full-	*(-a)* Rounded Indication Charts - relevant rounded indications characterized as imperfections shall not exceed those shown in Figures 7.5 through 7.10, which illustrate various types of assorted, randomly dispersed, and clustered rounded indications for different weld thicknesses greater than 3 mm (1/8 in.). The charts for each thickness range represent full-scale 150 mm

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scale 150 mm (6 in) radiographs and shall not be enlarged or reduced. The distributions shown are not necessarily the patterns that may appear on the radiograph but are typical of the concentration and size of indications permitted.	(6 in.) radiographs and shall not be enlarged or reduced. The distributions shown are not necessarily the patterns that may appear on the radiograph but are typical of the concentration and size of indications permitted.
ii) Relevant Indications (see Table 7.7 for examples) – only those rounded indications that exceed the following dimensions shall be considered relevant and compared to the acceptance charts for disposition.	*(-b)* Relevant Indications (See Table 7.7 for examples) - only those rounded indications that exceed the following dimensions shall be considered relevant and compared to the acceptance charts for disposition.
1. $t/10$ for t less than 3 mm (1/8 in)	*(-1)* $t/10$ for t less than 3 mm (1/8 in)
2. 0.4 mm (1/64 in) for t greater than or equal to 3 mm (1/8 in) and less than or equal to 6 mm (1/4 in)	*(-2)* 0.4 mm (1/64 in.) for t greater than or equal to 3 mm (1/8 in.) and less than or equal to 6 mm (1/4 in.)
3. 0.8 mm (1/32 in) for t greater than 6 mm (1/4 in) and less than or equal to 50 mm (2 in)	*(-3)* 0.8 mm (1/32 in.) for t greater than 6 mm (1/4 in.) and less than or equal to 50 mm (2 in.)
4. 1.5 mm (1/16 in) for t greater than 50 mm (2 in)	*(-4)* 1.5 mm (1/16 in.) for t greater than 50 mm (2 in.)
5. Maximum Size of Rounded Indication – the maximum permissible size of any indication shall be $t/4$ or 4 mm (5/32 in), whichever is smaller; except that an isolated indication separated from an adjacent indication by 25 mm (1 in) or more may be $t/3$, or 6 mm (1/4 in), whichever is less. For t greater than 50 mm (2 in) the maximum permissible size of an isolated indication shall be increased to 10 mm (3/8 in).	*(-5)* Maximum Size of Rounded Indication - the maximum permissible size of any indication shall be $t/4$ or 4 mm (5/32 in.), whichever is smaller; except that an isolated indication separated from an adjacent indication by 25 mm (1 in.) or more may be $t/3$, or 6 mm (1/4 in.), whichever is less. For t greater than 50 mm (2 in.) the maximum permissible size of an isolated indication shall be increased to 10 mm (3/8 in.).
6. Aligned Rounded Indications – aligned rounded indications are acceptable when the summation of the diameters of the indications is less than t in a length of $12t$ (see Figure 7.3). The length of groups of aligned rounded indications and the spacing between the groups shall meet the requirements of Figure 7.4.	*(-6)* Aligned Rounded Indications - aligned rounded indications are acceptable when the summation of the diameters of the indications is less than t in a length of $12t$ (See Figure 7.3). The length of groups of aligned rounded indications and the spacing between the groups shall meet the requirements of Figure 7.4.
7. Clustered Indications – the illustrations for clustered indications show up to four times as many indications in a local area, as that shown in the illustrations for random indications. The length of an acceptable cluster shall not exceed the lesser of 25 mm (1 in) or $2t$. Where more than one cluster is present, the sum of the lengths of the clusters shall not exceed 25 mm (1 in) in a 150 mm (6 in) length weld.	*(-7)* Clustered Indications - the illustrations for clustered indications show up to four times as many indications in a local area, as that shown in the illustrations for random indications. The length of an acceptable cluster shall not exceed the lesser of 25 mm (1 in.) or $2\ t$. Where more than one cluster is present, the sum of the lengths of the clusters shall not exceed 25 mm (1 in.) in a 150 mm (6 in.) length weld.
8. Weld Thickness t less than 3 mm (1/8 in) – for t less than 3 mm (1/8 in) the maximum number of rounded indications shall not exceed 12 in a 150 mm (6 in) length of weld. A proportionally fewer number of indications shall be permitted in welds less than 150 mm (6 in) in length.	*(-8)* Weld Thickness t less than 3 mm (1/8 in.) –for t less than 3 mm (1/8 in.) the maximum number of rounded indications shall not exceed 12 in a 150 mm (6 in.) length of weld. A proportionally fewer number of indications shall be permitted in welds less than 150 mm (6 in.) in length.
iii) Image Density – density or image brightness within the image of the indication may vary and is not a criterion for acceptance or rejection.	*(-c)* Image Density – density or image brightness within the image of the indication may vary and is not a criterion for acceptance or rejection.

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iv) Spacing – the distance between adjacent rounded indications is not a factor in determining acceptance or rejection, except as required for isolated indications or groups of aligned indications.	*(-d)* Spacing - the distance between adjacent rounded indications is not a factor in determining acceptance or rejection, except as required for isolated indications or groups of aligned indications.

Table 6.2 Ultrasonic examination acceptance standards in the 2007 and 2021 editions of Section I of the ASME BPVC

Ultrasonic Examination	
Section I – 2007 Edition	**Section I – 2021 Edition**
Part PW – Requirements for Boilers Fabricated by Welding	**Part PW – Requirements for Boilers Fabricated by Welding**
PW-52 Acceptance Standards for Ultrasonic Examination	**PW-52 Ultrasonic Examination**
PW-52.3 Acceptance-Rejection Standards Imperfections that cause an indication greater than 20% of the reference level shall be investigated to the extent that the ultrasonic examination personnel can determine their shape, identity, and location, and evaluate them in terms of PW-52.3.1 and PW-52.3.2.	**PW-52.3 Acceptance–Rejection Standards** Imperfections that cause an indication to exceed the evaluation levels specified in Section V shall be investigated to the extent that the ultrasonic examination personnel can determine their shape, identity, and location, and evaluate them in terms of PW-52.3.1 and PW-52.3.2.
PW-52.3.1 Cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.	**PW-52.3.1**. Cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.
PW-52.3.2 Other imperfections are unacceptable if the indication exceeds the reference level, and their length exceeds the following: *(a)* 1/4 in. (6 mm) for t up to 3/4 in. (19 mm) *(b)* 1/3t for t from 3/4 in. (19 mm) to 2 1/4 in. (57 mm) *(c)* 3/4 in. (19 mm) for t over 2 1/4 in. (57 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.	**PW-52.3.2** Other imperfections are unacceptable if the indication exceeds the reference level, and their length exceeds the following: *(a)* 1/4 in. (6 mm) for t up to 3/4 in. (19 mm) *(b)* 1/3t for t from 3/4 in. (19 mm) to 2 1/4 in. (57 mm) *(c)* 3/4 in. (19 mm) for t over 2 1/4 in. (57 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.
Section VIII, Division 1 – 2007 Edition	**Section VIII, Division 1 – 2021 Edition**
Part UW – Requirements for Pressure Vessels Fabricated by Welding	**Part UW – Requirements for Pressure Vessels Fabricated by Welding**
UW-53 Technique for Ultrasonic Examination of Welded Joints	**UW-53 Ultrasonic Examination of Welded Joints**
Ultrasonic examination of welded joints when required or permitted by other paragraphs of this Division shall be performed in accordance with Appendix 12 and shall be evaluated to the acceptance standards specified in Appendix 12.	**UW-53*(a)*** Ultrasonic examination of welded joints whose joint efficiency is not determined by ultrasonic examinations may be performed and evaluated in accordance with Mandatory Appendix 12.
	UW-53*(b)* Ultrasonic examination of welds per UW 51*(a)(4)* shall be performed and evaluated in accordance with the requirements of Section VIII, Division 2, 7.5.5.

Ultrasonic Examination	
Mandatory Appendix 12 Ultrasonic Examination of Welds (UT)	**Mandatory Appendix 12 Ultrasonic Examination of Welds (UT)**
12-3 Acceptance–Rejection Standards These Standards shall apply unless other standards are specified for specific applications within this Division. Imperfections which produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such imperfections and evaluate them in terms of the acceptance standards given in (a) and (b) below. *(a)* Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length. *(b)* Other imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths which exceed: *(1)* 1/4 in. (6 mm) for t up to 3/4 in. (19 mm) *(2)* 1/3 t for t from 3/4 in. to 2 1/4 in. (19 mm to 57 mm) *(3)* 3/4 in. (19 mm) for t over 2 1/4 in. (57 mm) where t is the thickness of the weld excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t.	**12-3 Acceptance–Rejection Standards** These Standards shall apply unless other standards are specified for specific applications within this Division. Imperfections which produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such imperfections and evaluate them in terms of the acceptance standards given in (a) and (b) below. *(a)* Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length. *(b)* Other imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths which exceed: *(1)* 1/4 in. (6 mm) for t up to 3/4 in. (19 mm) *(2)* 1/3 t for t from 3/4 in. to 2 1/4 in. (19 mm to 57 mm) *(3)* 3/4 in. (19 mm) for t over 2 1/4 in. (57 mm) where t is the thickness of the weld excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t.
Section VIII, Division 2 – 2007 Edition	**Section VIII, Division 2 – 2021 Edition**
Part 7 – Inspection and Examination Requirements	**Part 7 – Inspection and Examination Requirements**
Paragraph 7.5.4 Ultrasonic Examination	**Paragraph 7.5.4 Ultrasonic Examination**
Paragraph 7.5.4.2 Acceptance Criteria These standards shall apply unless other standards are specified for specific applications within this Division. All imperfections that produce an amplitude greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such imperfections and evaluate them in terms of the acceptance standards given in (a) and (b) below. *a)* Imperfections that are interpreted to be cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length. *b)* All other linear type imperfections are unacceptable if the amplitude exceeds the reference level, and the length of the imperfection exceeds the following: 1) 6 mm (1/4 in.) for t less than 19 mm (3/4 in.) 2) $t/3$ for t greater than or equal to 19 mm (3/4 in.) and less than or equal to 57 mm (2 1/4 in.) 3) 19 mm (3/4 in.) for t greater than 57 mm (2 1/4 in.)	**Paragraph 7.5.4.2 Acceptance Criteria** These standards shall apply unless other standards are specified for specific applications within this Division. All imperfections that produce an amplitude greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such imperfections and evaluate them in terms of the acceptance standards given in *(a)* and *(b)* below. *(a)* Imperfections that are interpreted to be cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length. *(b)* All other linear type imperfections are unacceptable if the amplitude exceeds the reference level, and the length of the imperfection exceeds the following: (1) 6 mm (1/4 in.) for t less than 19 mm (3/4 in.) (2) $t/3$ for t greater than or equal to 19 mm (3/4 in.) and less than or equal to 57 mm (2 1/4 in.) (3) 19 mm (3/4 in.) for t greater than 57 mm (2 1/4 in.)

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In the above criteria, t is the thickness of the weld, excluding any allowable reinforcement (see paragraph 6.2.4.1.d). For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t.	In the above criteria, t is as defined in 7.4.3.6.

Table 6.3 Magnetic particle examination acceptance standards in the 2007 and 2021 editions of Section I of the ASME BPVC

Magnetic Particle Examination	
Section I – 2007 Edition	**Section I – 2021 Edition**
Nonmandatory Appendix A – Explanation of the Code Containing Matter Not Mandatory Unless Specifically Referred to in the Rules of the Code	**Nonmandatory Appendix A – Explanation of the Code Containing Matter Not Mandatory Unless Specifically Referred to in the Rules of the Code**
Methods for Magnetic Particle Examination (MT) A-260	**Methods for Magnetic Particle Examination (MT) A-260**
A-260.4 Acceptance Standards. All surfaces to be examined shall be free of *(a)* relevant linear indications *(b)* relevant rounded indications greater than 3/16 in. (5 mm) *(c)* four or more relevant rounded indications in a line separated by 1/16 in. (1.5 mm) or less, edge to edge	**A-260.4 Acceptance Standards.** All surfaces to be examined shall be free of *(a)* relevant linear indications *(b)* relevant rounded indications greater than 3/16 in. (5 mm) *(c)* four or more relevant rounded indications in a line separated by 1/16 in. (1.5 mm) or less, edge to edge
Section VIII, Division 1 – 2007 Edition	**Section VIII, Division 1 – 2021 Edition**
Part UG – General Requirements for All Methods of Construction and All Materials	**Part UG – General Requirements for All Methods of Construction and All Materials**
UG-103 Nondestructive Testing Where magnetic particle examination is prescribed in this Division it shall be done in accordance with Mandatory Appendix 6. Where liquid penetrant examination is prescribed it shall be done in accordance with Mandatory Appendix 8.	**UG-103 Nondestructive Testing** Where magnetic particle examination is prescribed in this Division it shall be done in accordance with Mandatory Appendix 6. Where liquid penetrant examination is prescribed it shall be done in accordance with Mandatory Appendix 8.
Mandatory Appendix 6 Methods for Magnetic Particle Examination (MT)	**Mandatory Appendix 6 Methods for Magnetic Particle Examination (MT)**
6-4 Acceptance Standards These acceptance standards shall apply unless other more restrictive standards are specified for specific materials or applications within this Division. All surfaces to be examined shall be free of: *(a)* relevant linear indications *(b)* relevant rounded indications greater than 3/16 in. (5 mm) *(c)* four or more relevant rounded indications in a line separated by 1/16 in. (1.5 mm) or less, edge to edge	**6-4 Acceptance Standards** These acceptance standards shall apply unless other more restrictive standards are specified for specific materials or applications within this Division. All surfaces to be examined shall be free of: *(a)* relevant linear indications *(b)* relevant rounded indications greater than 3/16 in. (5 mm) *(c)* four or more relevant rounded indications in a line separated by 1/16 in. (1.5 mm) or less, edge to edge

Magnetic Particle Examination	
Section VIII, Division 2 – 2007 Edition	**Section VIII, Division 2 – 2021 Edition**
Part 7 – Inspection and Examination Requirements	**Part 7 – Inspection and Examination Requirements**
7.5.6 Magnetic Particle Examination (MT)	**7.5.6 Magnetic Particle Examination (MT)**
7.5.6.2 Acceptance Criteria The following acceptance standards shall apply unless other more restrictive standards are specified for specific material or applications within this Division. Unacceptable indications shall be removed or reduced to an indication of acceptable size. Whenever an indication is removed by chipping or grinding and subsequent repair by welding is not required, the excavated area shall be blended into the surrounding surface so as to avoid notches, crevices, or corners. Where welding is required after removal of indications, the repair shall be done in accordance with 6.2.7. (a) All surfaces to be examined shall be free of: (1) Relevant linear indications (2) Relevant rounded indications greater than 5 mm (3/16 in.) (3) Four or more relevant rounded indications in a line separated by 1.5 mm (1/16 in.) or less, edge-to-edge (b) Crack like indications detected, irrespective of surface conditions, are unacceptable.	**7.5.6.2 Acceptance Criteria** The following acceptance standards shall apply unless other more restrictive standards are specified for specific material or applications within this Division. Unacceptable indications shall be removed or reduced to an indication of acceptable size. Whenever an indication is removed by chipping or grinding and subsequent repair by welding is not required, the excavated area shall be blended into the surrounding surface so as to avoid notches, crevices, or corners. Where welding is required after removal of indications, the repair shall be done in accordance with 6.2.7. (a) All surfaces to be examined shall be free of: (1) Relevant linear indications (2) Relevant rounded indications greater than 5 mm (3/16 in.) (3) Four or more relevant rounded indications in a line separated by 1.5 mm (1/16 in.) or less, edge-to-edge (b) Crack like indications detected, irrespective of surface conditions, are unacceptable.

Table 6.4 Liquid penetrant examination acceptance standards in the 2007 and 2021 editions of Section I of the ASME BPVC

Liquid Penetrant Examination	
Section I – 2007 Edition	**Section I – 2021 Edition**
Nonmandatory Appendix A – Explanation of the Code Containing Matter Not Mandatory Unless Specifically Referred to in the Rules of the Code	**Nonmandatory Appendix A – Explanation of the Code Containing Matter Not Mandatory Unless Specifically Referred to in the Rules of the Code**
Methods for Liquid Penetrant Examination (MT) A-270	**Methods for Liquid Penetrant Examination (MT) A-270**
A-270.4 Acceptance Standards. All surfaces to be examined shall be free of *(a)* relevant linear indications *(b)* relevant rounded indications greater than 3/16 in. (5 mm) *(c)* four or more relevant rounded indications in a line separated by 1/16 in. (1.5 mm) or less, edge to edge	**A-270.4 Acceptance Standards.** All surfaces to be examined shall be free of *(a)* relevant linear indications *(b)* relevant rounded indications greater than 3/16 in. (5 mm) *(c)* four or more relevant rounded indications in a line separated by 1/16 in. (1.5 mm) or less, edge to edge
Section VIII, Division 1 – 2007 Edition	**Section VIII, Division 1 – 2021 Edition**
Part UG – General Requirements for All Methods of Construction and All Materials	**Part UG – General Requirements for All Methods of Construction and All Materials**
UG-103 Nondestructive Testing Where magnetic particle examination is prescribed in this Division it	**UG-103 Nondestructive Testing** Where magnetic particle examination is prescribed in this Division it

Liquid Penetrant Examination	
shall be done in accordance with Mandatory Appendix 6. Where liquid penetrant examination is prescribed it shall be done in accordance with Mandatory Appendix 8.	shall be done in accordance with Mandatory Appendix 6. Where liquid penetrant examination is prescribed it shall be done in accordance with Mandatory Appendix 8.
Mandatory Appendix 8 Methods for Liquid Penetrant Examination (PT)	**Mandatory Appendix 8 Methods for Liquid Penetrant Examination (PT)**
8-4 Acceptance Standards These acceptance standards shall apply unless other more restrictive standards are specified for specific materials or applications within this Division. All surfaces to be examined shall be free of: *(a)* relevant linear indications *(b)* relevant rounded indications greater than 3/16 in. (5 mm) *(c)* four or more relevant rounded indications in a line separated by 1/16 in. (1.5 mm) or less, edge to edge	**8-4 Acceptance Standards** These acceptance standards shall apply unless other more restrictive standards are specified for specific materials or applications within this Division. All surfaces to be examined shall be free of: *(a)* relevant linear indications *(b)* relevant rounded indications greater than 3/16 in. (5 mm) *(c)* four or more relevant rounded indications in a line separated by 1/16 in. (1.5 mm) or less, edge to edge
Section VIII, Division 2 – 2007 Edition	**Section VIII, Division 2 – 2021 Edition**
Part 7 – Inspection and Examination Requirements	**Part 7 – Inspection and Examination Requirements**
7.5.7 Liquid Penetrant Examination (PT)	**7.5.7 Liquid Penetrant Examination (PT)**
7.5.7.2 Acceptance Criteria The following acceptance standards shall apply unless other more restrictive standards are specified for specific material or applications within this Division. Unacceptable indications shall be removed or reduced to an indication of acceptable size. Whenever an indication is removed by chipping or grinding and subsequent repair by welding is not required, the excavated area shall be blended into the surrounding surface so as to avoid notches, crevices, or corners. Where welding is required after removal of indications, the repair shall be done in accordance with 6.2.7. (a) All surfaces to be examined shall be free of: (1) Relevant linear indications (2) Relevant rounded indications greater than 5 mm (3/16 in.) (3) Four or more relevant rounded indications in a line separated by 1.5 mm (1/16 in.) or less, edge-to-edge (b) Crack like indications detected, irrespective of surface conditions, are unacceptable.	**7.5.7.2 Acceptance Criteria** The following acceptance standards shall apply unless other more restrictive standards are specified for specific material or applications within this Division. Unacceptable indications shall be removed or reduced to an indication of acceptable size. Whenever an indication is removed by chipping or grinding and subsequent repair by welding is not required, the excavated area shall be blended into the surrounding surface so as to avoid notches, crevices, or corners. Where welding is required after removal of indications, the repair shall be done in accordance with 6.2.7. (a) All surfaces to be examined shall be free of: (1) Relevant linear indications (2) Relevant rounded indications greater than 5 mm (3/16 in.) (3) Four or more relevant rounded indications in a line separated by 1.5 mm (1/16 in.) or less, edge-to-edge (b) Crack like indications detected, irrespective of surface conditions, are unacceptable.

Table 6.5 Eddy current examination acceptance standards in the 2007 and 2021 editions of Section I of the ASME BPVC

Eddy Current Examination	
Section I – 2007 Edition	**Section I – 2021 Edition**
Not Applicable	**Not Applicable**

Eddy Current Examination	
Section VIII, Division 1 – 2007 Edition	**Section VIII, Division 1 – 2021 Edition**
Not Applicable	**Not Applicable**
Section VIII, Division 2 – 2007 Edition	**Section VIII, Division 2 – 2021 Edition**
Part 7 – Inspection and Examination Requirements	**Part 7 – Inspection and Examination Requirements**
7.5.8 Eddy Current Surface Examination Procedure Requirements (ET)	**7.5.8 Eddy Current Surface Examination Procedure Requirements (ET)**
7.5.8.8 Acceptance Standards These acceptance standards apply unless other more restrictive standards are specified for specific materials or applications within this Division. All surfaces examined shall be free of relevant ET surface flaw indications.	**7.5.8.8 Acceptance Standards** These acceptance standards apply unless other more restrictive standards are specified for specific materials or applications within this Division. All surfaces examined shall be free of relevant ET surface flaw indications.

6.2.4.1 Comparison of NDE Acceptance Standards in Section I

Acceptance standards provided in Section I in the 2007 and 2021 editions of the ASME BPVC for radiographic, ultrasonic, magnetic particle, and liquid penetrant examinations are compared in Tables 6.1 through 6.4 of this report. However, evaluation level requirements for ultrasonic examinations provided in Paragraph PW-52.3 in the 2021 edition are more comprehensive and clearly defined than the evaluation level requirements in the 2007 edition.

6.2.4.2 Comparison of NDE Acceptance Standards in Section VIII, Division 1

As Tables 6.1 through 6.4 of this report show, acceptance standards provided in Section VIII, Division 1 for radiographic, ultrasonic, magnetic particle, and liquid penetrant examinations are comparable. However, compared to the 2007 edition, acceptance standards for radiographic examinations in the 2021 edition of Section VIII, Division 1 were expanded for both linear and rounded indications. In addition, ultrasonic examination criteria were added to the 2021 edition of Section VIII, Division 1 as an alternative to radiographic examinations for welded joints.

6.2.4.3 Comparison of NDE Acceptance Standards in Section VIII, Division 2

As Tables 6.1 through 6.5 of this report show, acceptance standards provided in Section VIII, Division 2 for radiographic, ultrasonic, magnetic particle, liquid penetrant, and eddy current examinations are comparable. However, compared to the 2007 edition, acceptance standards for radiographic examinations provided in Paragraph 7.5.3.2 in the 2021 edition of Section VIII, Division 2 were expanded to include groups of linear indications and more well-defined shape characteristics of rounded indications.

6.2.4.4 Acceptance Criteria for Visual Examination

Acceptance criteria for visual examination are provided in Paragraph 7.5.2.2 in the 2007 and 2021 editions in the Section VIII, Division 2 of the ASME BPVC. This paragraph states that welds that are observed to have indications exceeding the criteria given in Table 7.6 – Visual Examination Acceptance Criteria are unacceptable. Unacceptable indications shall be removed or reduced to an indication of acceptable size. Whenever an indication is removed by chipping or grinding and subsequent repair by welding is not required, the area shall be blended into the surrounding surface so as to avoid notches, crevices, or corners. Where welding is required after removal of indications, the repair shall be done in accordance with 6.2.7 – Repair of Weld Defects. Additional visual examination requirements provided in Section V, Article 9 – Visual Examination are discussed in Sect. 6.3.7 of this report.

Acceptance standards for visual examinations are not provided in Section I or Section VIII, Division 1 of the ASME BPVC.

6.2.5 Crosswalk of Qualification and Certification Requirements for NDE Personnel

As discussed in Sect. 6.1 of this report, the Manufacturer is responsible for training, qualifying, and certifying of NDE personnel that perform NDE methods and evaluate NDE results. Requirements for qualification and certification for NDE personnel that are provided in Section I; Section VIII, Division 1; and Section VIII, Division 2 of the ASME BPVC are discussed in Sects. 6.2.1, 6.2.2, and 6.2.3 of this report, respectively. Table 6.6 of this report is a crosswalk that maps paragraphs in Section I; Section VIII, Division 1; and Section VIII, Division 2 that provide qualification and certification requirements for NDE personnel to sections referenced in this report where these qualification and certification requirements are examined and explained. Based on equivalent safety evaluations results, these requirement changes do not violate the fundamental safety assumptions stated or implied in the 2007 edition of the ASME BPVC and therefore provide equivalent safety.

Table 6.6 Paragraphs in the ASME BPVC that provide qualifications or certifications requirements for NDE personnel

NDE Method	Edition	Paragraphs that Provide Qualification or Certification Requirements for NDE Personnel	Reference Section of this Report
		Section I	
VT	2021	PW-44 – Fabrication Rules for Bimetallic Tubes When the Clad Strength is Included, Paragraph PW-44.8.1	6.2.1.5
VT	2021	Paragraph PG-75 General	6.2.1.5
RT	2007 2021	PW-50 – Qualification of Nondestructive Examination Personnel, Paragraph PW-50.1	6.2.1
UT	2007 2021	PW-50 – Qualification of Nondestructive Examination Personnel, Paragraph PW-50.1	6.2.1
MT	2007 2021	Nonmandatory Appendix A – Explanation of the Code Containing Matter Not Mandatory Unless Specifically Referred to in the Rules of the Code, Paragraph A-260	6.2.1
PT	2007 2021	Nonmandatory Appendix A – Explanation of the Code Containing Matter Not Mandatory Unless Specifically Referred to in the Rules of the Code, Paragraph A-270	6.2.1
ET		Not Applicable	
		Section VIII, Division 1	
VT	2021	Part UIG – Requirements for Pressure Vessels Constructed of Impregnated Graphite, Paragraph UIG-96 – Qualification of Visual Examination Personnel	6.2.2
RT	2021	Part UW – Requirements for Pressure Vessels Fabricated by Welding, Paragraph UW-54 – Qualification of Nondestructive Examination Personnel	6.2.2
RT	2007	Part UW – Requirements for Pressure Vessels Fabricated by Welding, Paragraph UW-51 – Radiographic Examination of Welded Joints	6.2.2

NDE Method	Edition	Paragraphs that Provide Qualification or Certification Requirements for NDE Personnel	Reference Section of this Report
UT	2021	Part UW – Requirements for Pressure Vessels Fabricated by Welding, Paragraph UW-54 – Qualification of Nondestructive Examination Personnel	6.2.2
UT	2007	Mandatory Appendix 12 – Ultrasonic Examination of Welds (UT), Paragraph 12-2 – Certification of Competence of Nondestructive Examiner	6.2.2
MT	2007 2021	Mandatory Appendix 6 – Methods for Magnetic Particle Examination (MT), Paragraph 6-2 – Certification of Competency of Nondestructive Examination Personnel in the 2007 edition	6.2.2
PT	2007 2021	Mandatory Appendix 8 – Methods for Liquid Penetrant Examination (PT), Paragraph 8-2 – Certification of Competency of Nondestructive Examination Personnel	6.2.2
ET		Not Applicable	
Section VIII, Division 2			
VT	2007 2021	Part 7 – Inspection and Examination Requirements, Paragraph 7.5.2 – Visual Examination	6.2.3.6
RT	2021	Part 7 – Inspection and Examination Requirements, Paragraph 7.3 – Qualification of Nondestructive Examination Personnel	6.2.3.1
RT	2007	Part 7 – Inspection and Examination Requirements, Paragraph 7.5.3 – Radiographic Examination	6.2.3.1
UT	2021	Part 7 – Inspection and Examination Requirements, Paragraph 7.3 – Qualification of Nondestructive Examination Personnel	6.2.3.2
UT	2007	Part 7 – Inspection and Examination Requirements, Paragraph 7.5.4 – Ultrasonic Examination and Paragraph 7.5.5 – Ultrasonic Examination Used In lieu of Radiographic Examination	6.2.3.2
MT	2021	Part 7 – Inspection and Examination Requirements, Paragraph 7.3 – Qualification of Nondestructive Examination Personnel	6.2.3.3
MT	2007	Part 7 – Inspection and Examination Requirements, Paragraph 7.5.6 Magnetic Particle Examination (MT)	6.2.3.3
PT	2021	Part 7 – Inspection and Examination Requirements, Paragraph 7.3 – Qualification of Nondestructive Examination Personnel	6.2.3.4
PT	2007	Part 7 – Inspection and Examination Requirements, Paragraph 7.5.7 Liquid Penetrant Examination (PT)	6.2.3.4
ET	2021	Part 7 – Inspection and Examination Requirements, Paragraph 7.3 – Qualification of Nondestructive Examination Personnel	6.2.3.5
ET	2007	Part 7 – Inspection and Examination Requirements, Paragraph 7.5.8 Eddy Current Surface Examination Procedure Requirements (ET)	6.2.3.5

6.3 NDE TECHNOLOGY

Nondestructive evaluation technology involves the use of noninvasive techniques to evaluate the integrity of a material, component, or structure and to locate and quantify imperfections that could adversely affect the ability of the item to perform its intended function. Successful implementation of NDE technology results in no damage to the material, component, or structure.

Section I; Section VIII, Division 1; and Section VIII, Division 2 of the ASME BPVC incorporate the following NDE methods into rules and requirements for evaluating the acceptability of boiler and pressure vessel construction.

- Eddy Current – ET
- Liquid Penetrant Examination – PT
- Magnetic Particle Examination – MT
- Radiographic Examination – RT
- Ultrasonic Examination – UT
- Visual Examination – VT

These NDE methods are capable of detecting imperfections that require evaluation where the term evaluation means the determination of whether a relevant indication is the reason to accept or to reject a material or component. Table 6.7 of this report identifies common types of imperfections found in welded construction and the NDE methods that may be used to detect these imperfections.

Table 6.7 NDE methods capable of detecting imperfections in welded construction

Imperfection†	NDE Method
Burn Through	VT, RT
Cracks	PT, MT, UT, ET
Excessive/Inadequate Reinforcement	VT, RT
Inclusions (Slag/Tungsten)	RT, ET
Incomplete Fusion	UT, ET
Incomplete Penetration	PT, MT, RT, UT, ET
Misalignment	VT, RT
Overlap	PT, MT
Porosity	VT, PT, RT
Root Concavity	VT, RT
Undercut	VT, RT

†An imperfection is a departure of a quality characteristic from its intended condition.

Nondestructive examination requirements specified in Section I; Section VIII, Division 1; and Section VIII, Division 2 of the ASME BPVC often incorporate examination and documentation requirements specified in Section V of the ASME BPVC. However, these Construction Codes may supplement the requirements specified in Section V with additional requirements that are more restrictive or take exceptions to requirements provided in Section V.

Section V in the 2007 and 2021 editions of the ASME BPVC is arranged into Subsection A – Nondestructive Methods of Examination and Subsection B – Documents Adopted by Section V. Subsection A is organized into Articles, mandatory appendices, and nonmandatory appendices that provide requirements for a particular NDE method. It describes the NDE methods to be used if referenced by a Construction Code or referencing documents. Subsection B lists standards that cover NDE methods. These standards, which are generally identical to ASTM specifications, are not mandatory unless specifically referenced in whole or in part in Subsection A or as indicated in a Construction Code or referencing documents.

6.3.1 General NDE Requirements in Section V

Article 1 – General Requirements in the 2007 and 2021 editions of Section V of the ASME BPVC provide general requirements and methods for NDE which are Code requirements to the extent they are specifically referenced and required by a Construction Code or referencing documents. These NDE methods are used to detect surface and internal imperfections in materials, welds, fabricated parts, and components.

Rules for certification of NDE personnel are specified in Paragraphs T-120*(e)* and *(f)* in the 2021 edition of Section V of the ASME BPVC. These rules state:

> *(e) For those documents that directly reference this Article for the qualification of NDE personnel, the qualification shall be in accordance with their employer's written practice which shall be in accordance with one of the following documents:*
>
> > *(1) SNT-TC-1A (2016 Edition), Personnel Qualification and Certification in Nondestructive Testing, as amended by Mandatory Appendix III; or*
> >
> > *(2) ANSI/ASNT CP-189 (2016 Edition), ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel, as amended by Mandatory Appendix IV*
>
> *(f) National or international central certification programs, such as the ASNT Central Certification Program (ACCP) or ISO 9712:2012-based programs, may be alternatively used to fulfill the training, experience, and examination requirements of the documents listed in (e) as specified in the employer's written practice.*

By comparison, Paragraph T-120*(e)* in the 2007 edition of Section V of the ASME BPVC specified the 2001 editions of SNT-TC-1A and ANSI/ASNT CP-189, and Paragraph T-120*(f)* in the 2007 edition of Section V of the ASME BPVC added ISO 9712:2012-based programs as an example of a National or international central certification program.

Addition rules for certification of NDE personnel are provided in Paragraphs T-120*(g)* and *(h)* in the 2021 edition of Section V of the ASME BPVC. These rules state:

> *(g) In addition to the requirements described in (e) or (f) above, if the techniques of computed radiography (CR), digital radiography (DR), phased-array ultrasonic (PAUT), ultrasonic time-of-flight diffraction (TOFD), or ultrasonic full matrix capture (FMC) are to be used, the training, experience, and examination requirements found in Article 1, Mandatory Appendix II shall also be included in the employer's written practice for each technique as applicable.*
>
> *(h) Alternatively, performance-based qualification programs, in accordance with ASME ANDE-1-2015, ASME Nondestructive Examination and Quality Control Central Qualification and Certification Program, may be used for training, experience, examination, and certification activities as specified in the written practice.*

The alternative rules for performance-based qualification programs permitted in Paragraphs T-120(*h*) in the 2021 edition of Section V are not included in the 2007 edition of Section V of the ASME BPVC.

Paragraph T-150 – Procedure in the 2007 and 2021 editions of Section V of the ASME BPVC specifies the following rules that apply to all NDE methods. Paragraph T-150*(a)* states:

> *When required by the referencing Code Section, all nondestructive examinations performed under this Code Section shall be performed following a written procedure. A procedure*

demonstration shall be performed to the satisfaction of the Inspector. When required by the referencing Code Section, a personnel demonstration may be used to verify the ability of the examiner to apply the examination procedure. The examination procedure shall comply with the applicable requirements of this Section for the particular examination method. Written procedures shall be made available to the Inspector on request. At least one copy of each procedure shall be readily available to the Nondestructive Examination Personnel for their reference and use.

Additional general requirements in Section V, Article 1 are provided in the following mandatory appendices.

- Mandatory Appendix I – Glossary of Terms for Nondestructive Examination (provided in 2007 and 2021 edition)
- Mandatory Appendix II – Supplemental Personnel Qualification Requirements for NDE Certification (provided in 2021 edition)
- Mandatory Appendix II – Supplement A (provided in 2021 edition)
- Mandatory Appendix III – Exceptions and Additional Requirements for Use of ASNT SNT-TC-1A 2016 Edition (provided in 2021 edition)
- Mandatory Appendix IV – Exceptions to ASNT/ANSI CP-189 2016 Edition (provided in 2021 edition)

Mandatory Appendix I establishing standard terms and the definitions of those terms for Section V. The terms and definitions provided in this appendix apply to the NDE methods and techniques described in Section V and are grouped by examination method.

Mandatory Appendix II provides the additional personnel qualification requirements that are mandated by Article 1, T-120*(g)*, and which are to be included in the employer's written practice for NDE personnel certification, when any of the following techniques are used by the employer: computed radiography (CR), digital radiography (DR), phased array ultrasonic (PAUT), ultrasonic time of flight diffraction (TOFD), and ultrasonic full matrix capture (FMC).

Mandatory Appendix II – Supplement A provides a training outline for Level II personnel.

Mandatory Appendix III provides exceptions and additional requirements for use of ASNT SNT-TC-1A 2016 edition.

Mandatory Appendix IV identifies exceptions to 2016 Edition of ASNT/ANSI CP-189 requirements for "Qualification and Certification of Nondestructive Testing Personnel." The requirements identified in this Mandatory Appendix take exception to those specific requirements as identified in the 2016 Edition of ASNT/ANSI CP-189 document.

6.3.2 Radiographic Examination Requirements in Section V

A radiographic examination is a noninvasive NDE method used to detect imperfections in materials by passing X-ray or nuclear radiation through the material and presenting their image on a recording medium. As Table 6.7 of this report shows, common weld imperfections detectable by radiographic examination include burn through, excessive/inadequate reinforcement, inclusions, incomplete penetration, misalignment, porosity, root concavity, and undercut.

Article 2 – Radiographic Examination in the 2007 and 2021 editions of Section V of the ASME BPVC provides requirements for radiographic examination of materials including castings and welds. The extent of radiographic examinations is as specified by the referencing Construction Code. Product-specific, technique-specific, and application-specific requirements are also provided in the following mandatory appendices provided in Section V, Article 2.

- Mandatory Appendix I – In-Motion Radiography (provided in 2007 and 2021 edition)
- Mandatory Appendix II – Real-Time Radioscopic Examination (provided in 2007 and 2021 edition)
- Mandatory Appendix III – Digital Image Acquisition, Display, and Storage for Radiography and Radioscopy (provided in 2007 and 2021 edition)
- Mandatory Appendix IV – Interpretation, Evaluation, and Disposition of Radiographic and Radioscopic Examination Test Results Produced by the Digital Image Acquisition and Display Process (provided in 2007 and 2021 edition)
- Mandatory Appendix V – Glossary of Terms for Radiographic Examination (provided in 2007 edition and incorporated into Article 1, Mandatory Appendix I – Glossary of Terms for Nondestructive Examination in the 2021 edition)
- Mandatory Appendix VI – Acquisition, Display, Interpretation, and Storage of Digital Images of Radiographic Film for Nuclear Applications (provided in 2007 and 2021 edition)
- Mandatory Appendix VI – Supplement A (provided in 2021 edition)
- Mandatory Appendix VII – Radiographic Examination of Metallic Castings (provided in 2007 and 2021 edition)
- Mandatory Appendix VIII – Radiography Using Phosphor Imaging Plate (provided in 2007 and 2021 edition)
- Mandatory Appendix VIII – Supplement A (provided in 2021 edition)
- Mandatory Appendix IX – Radiography Using Digital Detector Systems (provided in 2021 edition)
- Mandatory Appendix IX – Supplement A (provided in 2021 edition)

Paragraph III-210 in Mandatory Appendix III in the 2007 and 2021 editions of Section V of the ASME BPVC states:

> *Digital image acquisition, display, and storage can be applied to radiography and radioscopy. Once the analog image is converted to digital format, the data can be displayed, processed, quantified, stored, retrieved, and converted back to the original analog format, for example, film or video presentation.*

This requirement in Mandatory Appendix III only applies to digital image acquisition, display, and storage for radiography and radioscopy and not to digital radiography (DR) techniques as an alternative to film radiography.

Rules in Paragraph IX-210 – Scope in Mandatory Appendix IX – Radiography Using Digital Detector Systems in the 2021 edition of Section V of the ASME BPVC specify requirements for the use of direct radiography (DR) techniques using digital detector systems (DDSs), where the image is transmitted directly from the detector rather than using an intermediate process for conversion of an analog image to a digital format. Mandatory Appendix IX also addresses applications in which the radiation detector, the source of the radiation, and the object being radiographed may or may not be in motion during exposure. Section V, Article 2 provisions apply unless modified by Mandatory Appendix IX.

Radiography using digital detector systems as specified in Mandatory Appendix IX in the 2021 edition of Section V of the ASME BPVC is permitted as an alternative to digital image acquisition as provided in

Mandatory Appendix III – Digital Image Acquisition, Display, and Storage for Radiography and Radioscopy in the 2007 and 2021 edition of Section V of the ASME BPVC. As noted above, the 2007 edition of Section V of the ASME BPVC does not include Mandatory Appendix IX – Application of Digital Radiography and Mandatory Appendix IX – Supplement A.

Computed radiography (CR) and digital radiography (DR) are commonly used terms for digital radiographic detectors. Computed radiography uses a photostimulable storage phosphor that stores the latent image with subsequent processing using a stimulating laser beam and can be easily adapted to a cassette-based system analogous to that used in screen-film radiography. Historically, DR has been used to describe a digital X-ray imaging system that reads the transmitted X-ray signal immediately after exposure with the detector in place. Use of CR or DR provides equivalent or greater safety compared to use of film radiography and digital image acquisition provided NDE personnel are qualified and certified in the use of these methods.

6.3.3 Ultrasonic Examination Requirements in Section V

An ultrasonic examination is a noninvasive NDE method used to detect imperfections in materials by passing ultrasonic vibrations (frequencies normally 1 MHz to 5 MHz) through the material. As Table 6.7 of this report shows, common weld imperfections detectable by this method include cracks, incomplete fusion, and incomplete penetration.

Paragraph T-410 – Scope in Article 4 – Ultrasonic Examination Methods for Welds in the 2007 and 2021 editions of Section V of the ASME BPVC provides or references requirements for weld examinations. These requirements are used in selecting and developing ultrasonic examination procedures when examination to any part of this Article is a requirement of a referencing Code Section. These procedures are to be used for ultrasonic examinations and for dimensioning of indications for comparison with acceptance standards. Paragraph T-421 – Written Procedure Requirements states that ultrasonic examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table T-421 – Requirements of an Ultrasonic Examination Procedure or the Mandatory Appendices applicable to the technique in use. Product-specific, technique-specific, and application-specific requirements are also provided in the following mandatory appendices in Section V, Article 4.

- Mandatory Appendix I – Screen Height Linearity (provided in 2007 and 2021 edition)
- Mandatory Appendix II – Amplitude Control Linearity (provided in 2007 and 2021 edition)
- Mandatory Appendix III – Time of Flight Diffraction (TOFD) Technique (provided in 2007 and 2021 edition)
- Mandatory Appendix IV – Phased Array Manual Raster Examination Techniques Using Linear Arrays (provided in 2007 and 2021 edition)
- Mandatory Appendix V – Phased Array E-Scan and S-Scan Linear Scanning Examination Techniques (provided in 2021 edition)
- Mandatory Appendix VII – Ultrasonic Examination Requirements for Workmanship Based Acceptance Criteria (provided in 2021 edition)
- Mandatory Appendix VIII – Ultrasonic Examination Requirements for a Fracture Mechanics Based Acceptance Criteria (provided in 2021 edition)
- Mandatory Appendix IX – Procedure Qualification Requirements for Flaw Sizing and Categorization (provided in 2021 edition)

- Mandatory Appendix X – Ultrasonic Examination of High Density Polyethylene (provided in 2021 edition)
- Mandatory Appendix XI – Full Matrix Capture (provided in 2021 edition)

Requirements provided in Article 4, Paragraph T-420 – General in the 2021 editions of Section V of the ASME BPVC was expanded from the 2007 edition to state:

> *The requirements of this Article shall be used together with Article 1, General Requirements. Refer to:*
>
> *(a) special provisions for coarse grain materials and welds in T-451* (provided in 2007 and 2021 editions)
>
> *(b) special provisions for computerized imaging techniques in T-452* (provided in 2007 and 2021 editions)
>
> *(c) Mandatory Appendix III for Time of Flight Diffraction (TOFD) techniques* (provided in 2021 edition)
>
> *(d) Mandatory Appendix IV for phased array manual rastering techniques* (provided in 2021 edition)
>
> *(e) Mandatory Appendix V for phased array E-scan and S-scan linear scanning examination techniques* (provided in 2021 edition)
>
> *(f) Mandatory Appendix XI for full matrix capture (FMC) techniques* (provided in 2021 edition)

Mandatory Appendix III provides requirements to be used for a Time of Flight Diffraction (TOFD) examination of welds.

Mandatory Appendix IV provides requirements to be used for phased array, manual raster scanning, ultrasonic techniques using linear arrays.

Mandatory Appendix V provides requirements to be used for phased array E-scan (fixed angle) and S-scan encoded linear scanning examinations using linear array search units.

Mandatory Appendix XI provides the requirements for using the full matrix capture (FMC) ultrasonic technique, in conjunction with data reconstruction techniques, when examinations are performed for fracture-mechanics-based acceptance criteria. A general description of FMC data and data reconstruction techniques is given in Article 4, Nonmandatory Appendix F – Examination of Welds Using Full Matrix Capture.

6.3.4 Magnetic Particle Examination Requirements in Section V

A magnetic particle examination is a noninvasive NDE method used to detect cracks and other discontinuities on the surfaces of ferromagnetic materials. As Table 6.7 of this report shows, common weld imperfections detectable by this method include cracks, incomplete penetration, and overlap. The sensitivity of a magnetic particle examination is greatest for surface discontinuities and diminishes rapidly with increasing depth of discontinuities below the surface.

In principle, the magnetic particle examination method involves magnetizing an area to be examined and applying ferromagnetic particles (the examination's medium) to the surface. Particle patterns form on the surface where the magnetic field is forced out of the part and over discontinuities to cause a leakage field that attracts the particles. Particle patterns are usually characteristic of the type of discontinuity that is detected. Whichever technique is used to produce the magnetic flux in the part, maximum sensitivity corresponds to linear discontinuities oriented perpendicular to the lines of flux. For optimum effectiveness in detecting all types of discontinuities, each area is to be examined at least twice, with the lines of flux during one examination being approximately perpendicular to the lines of flux during the other.

Article 7 – Magnetic Particle Examination, Paragraph T-710 – Scope in the 2007 and 2021 editions of Section V of the ASME BPVC states that the magnetic particle examination techniques described in this Article must be used together with Article 1 – General Requirements when specified by the referencing Construction Code. Requirements in T-721 – Written Procedure Requirements states that magnetic particle examination shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table T-721 – Requirements of a Magnetic Particle Examination Procedure. Additional magnetic particle examination requirements are provided in the 2021 editions of Article 7, Section V of the ASME BPVC in the following mandatory appendices.

- Mandatory Appendix I – Magnetic Particle Examination Using the AC Yoke Technique on Ferritic Materials Coated with Nonmagnetic Coatings (provided in 2007 and 2021 editions)
- Mandatory Appendix II – Glossary of Terms for Magnetic Particle Examination (provided in 2007 edition and incorporated into Article 1, Mandatory Appendix I – Glossary of Terms for Nondestructive Examination in the 2021 edition)
- Mandatory Appendix III – Magnetic Particle Examination Using the Yoke Technique with Fluorescent Particles in an Undarkened Area (provided in 2007 and 2021 editions)
- Mandatory Appendix IV – Qualification of Alternate Wavelength Light Sources for Excitation of Fluorescent Particles (provided in 2021 edition)
- Mandatory Appendix V – Requirements for the Use of Magnetic Rubber Techniques (provided in 2021 edition)

Mandatory Appendix IV describes the methodology to qualify the performance of fluorescent particle examinations using alternate wavelength sources.

Mandatory Appendix V describes the methodology and equipment requirements applicable for performing magnetic particle examinations using magnetic rubber techniques in place of wet or dry magnetic particles. The principal applications for this technique are:

(a) limited visual or mechanical accessibility, such as bolt holes

(b) coated surfaces

(c) complex shapes or poor surface conditions

(d) discontinuities that require magnification for detection and interpretation

(e) permanent record of the actual inspection

6.3.5 Liquid Penetrant Examination Requirements in Section V

A liquid penetrant examination is a noninvasive NDE method used to detect discontinuities which are open to the surface of nonporous metals and other materials. As Table 6.7 of this report shows, common weld imperfections detectable by this method include cracks, incomplete penetration, overlap, and porosity. In principle, a liquid penetrant is applied to the surface to be examined and allowed to enter discontinuities. All excess penetrant is then removed, the part is dried, and a developer is applied. The developer functions as a blotter to absorb penetrant that has been trapped in discontinuities, and as contrasting background to enhance the visibility of penetrant indications. The dyes in penetrants are either color contrast (visible under white light) or fluorescent (visible under ultraviolet light).

Article 6 – Liquid Penetrant Examination, Paragraph T-610 – Scope in the 2007 and 2021 editions of Section V of the ASME BPVC states that when this Article is specified by a referencing Code Section, the liquid penetrant method described in Article 6 shall be used together with Article 1 – General Requirements. Requirements in Paragraph T-621 – Written Procedure Requirements states that liquid penetrant examination shall be performed in accordance with a written procedure which shall as a minimum, contain the requirements listed in Table T-621.1 – Requirements of a Liquid Penetrant Examination Procedure. Additional liquid penetrant examination requirements are provided in the following are mandatory appendices.

- Mandatory Appendix I – Glossary of Terms for Liquid Penetrant Examination (provided in 2007 edition and incorporated into Article 1, Mandatory Appendix I – Glossary of Terms for Nondestructive Examination in the 2021 edition)
- Mandatory Appendix II – Control of Contaminants for Liquid Penetrant Examination (provided in 2007 and 2021 editions)
- Mandatory Appendix III – Qualification Techniques for Examinations at Nonstandard Temperatures (provided in 2007 and 2021 editions)

6.3.6 Eddy Current Surface Examination Requirements in Section V

An eddy current surface examination is one of several noninvasive NDE techniques that uses the electromagnetism principle for flaw detection in conductive-nonferromagnetic and coated ferromagnetic materials. As Table 6.7 of this report shows, common weld imperfections detectable by this method include cracks, inclusions, incomplete fusion, and incomplete penetration.

Article 8 – Eddy Current Examination in the 2007 and 2021 editions of Section V of the ASME BPVC states that the eddy current examination method and techniques described in this Article shall be used when specified by the referencing Code Section. Additional eddy current examination requirements are provided in the following are mandatory appendices.

- Mandatory Appendix I – Glossary of Terms for Eddy Current Examination (provided in 2007 edition and incorporated into Article 1, Mandatory Appendix I – Glossary of Terms for Nondestructive Examination in the 2021 edition)
- Mandatory Appendix II – Eddy Current Examination of Nonferromagnetic Heat Exchanger Tubing (provided in 2007 and 2021 editions)
- Mandatory Appendix III – Eddy Current Examination on Coated Ferritic Materials (provided in 2007 and 2021 editions)
- Mandatory Appendix IV – External Coil Eddy Current Examination of Tubular Products (provided in 2007 and 2021 editions)
- Mandatory Appendix V – Eddy Current Measurement of Nonconductive-Nonmagnetic Coating Thickness on a Nonmagnetic Metallic Material (provided in 2007 and 2021 editions)
- Mandatory Appendix VI – Eddy Current Detection and Measurement of Depth of Surface Discontinuities in Nonmagnetic Metals with Surface Probes (provided in 2007 and 2021 editions)
- Mandatory Appendix VII – Eddy Current Examination of Ferromagnetic and Nonferromagnetic Conductive Metals to Determine If Flaws Are Surface Connected (provided in 2021 edition)
- Mandatory Appendix VIII – Alternative Technique for Eddy Current Examination of Nonferromagnetic Heat Exchanger Tubing, Excluding Nuclear Steam Generator Tubing (provided in 2021 edition)

- Mandatory Appendix IX – Eddy Current Array Examination of Ferromagnetic and Nonferromagnetic Materials for the Detection of Surface-Breaking Flaws (provided in 2021 edition)
- Mandatory Appendix X – Eddy Current Array Examination of Ferromagnetic and Nonferromagnetic Welds for the Detection of Surface-Breaking Flaws (provided in 2021 edition)

Mandatory Appendix VII provides the requirements for eddy current examination with a surface probe to determine if flaws are surface connected in both ferromagnetic and nonferromagnetic metals.

Mandatory Appendix VIII provides the requirements for an alternative technique for bobbin coil multifrequency and multiparameter eddy current examination of installed nonferromagnetic heat exchanger tubing, excluding nuclear steam generator tubing.

Mandatory Appendix IX provides the requirements for eddy current array (ECA) surface probe examination of coated and noncoated ferromagnetic and nonferromagnetic materials for the detection of surface-breaking flaws.

Mandatory Appendix X provides the requirements for ECA surface probe examination of coated and noncoated ferromagnetic and nonferromagnetic welds for the detection of surface-breaking flaws.

6.3.7 Visual Examination Requirements in Section V

A visual examination is a noninvasive NDE method used to evaluate an item by observation. Visual examinations can be effective in evaluating correct assembly and verifying compliance with applicable requirements such as dimensions, joint preparation, alignment prior to welding or joining, finished weld conditions, and leak detection based on acceptance standards provided in the referencing Code Section. Common weld imperfections detectable by this method include burn through, excessive/inadequate reinforcement, misalignment, porosity, root concavity, and undercut.

Article 9 – Visual Examination, Paragraph T-910 – Scope in the 2007 and 2021 editions of Section V of the ASME BPVC states that methods and requirements for visual examination in this Article are applicable together with requirements of Article 1 – General Requirements when specified by a referencing Construction Code. Specific visual examination procedures required for every type of examination are not included in this Article because there are many applications where visual examinations are required. The requirements of Article 1 – General Requirements, apply whenever visual examination, in accordance with Article 9 – Visual Examination, is required by a referencing Code Section.

Visual inspection is implied throughout the ASME BPVC and only explicitly stated as a requirement for examination of specific components. Section I; Section VIII, Division 1; and Section VIII, Division 2 of the ASME BPVC generally invoke visual examination procedures contained in Section V. As an example, Part 7 – Inspection and Examination Requirements, Paragraph 7.5.2.1 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC states that all welds for pressure retaining parts must be visually examined. Acceptance criteria for visual examination are provided in Paragraph 7.5.2.2 in the 2007 and 2021 editions in the Section VIII, Division 2 of the ASME BPVC.

Requirements in T-921 – Written Procedure Requirements states that visual examinations shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table T-921 – Requirements of a Visual Examination Procedure.

6.4 LEAK TESTING

Section V, Article 10 – Leak Testing in the 2007 and 2021 editions of the ASME BPVC describes methods and requirements for performing leak tests. These leak test methods can be used to locate leaks or measure leakage rates. When a leak testing method or technique is specified by a referencing Code Section, the leak test method prescribed in Section V, Article 10 are to be used together with Section V, Article 1 – General Requirements. Rules for leak test methods and technique included in Section V, Article 10 are provided in the following mandatory appendices.

- Mandatory Appendix I – Bubble Test — Direct Pressure Technique (provided in 2007 and 2021 editions)
- Mandatory Appendix II – Bubble Test —Vacuum Box Technique (provided in 2007 and 2021 editions)
- Mandatory Appendix III – Halogen Diode Detector Probe Test (provided in 2007 and 2021 editions)
- Mandatory Appendix IV – Helium Mass Spectrometer Test — Detector Probe Technique (provided in 2007 and 2021 editions)
- Mandatory Appendix V – Helium Mass Spectrometer Test —Tracer Probe Technique (provided in 2007 and 2021 editions)
- Mandatory Appendix VI – Pressure Change Test (provided in 2007 and 2021 editions)
- Mandatory Appendix VIII – Thermal Conductivity Detector Probe Test (provided in 2007 and 2021 editions)
- Mandatory Appendix IX – Helium Mass Spectrometer Test — Hood Technique (provided in 2007 and 2021 editions)
- Mandatory Appendix X – Ultrasonic Leak Detector Test (provided in 2007 and 2021 editions)
- Mandatory Appendix XI – Helium Mass Spectrometer — Helium-Filled-Container Leakage Rate Test (provided in 2021 edition)

Requirements in Article 10, Paragraph T-1021.1 – Requirements state that leak testing shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in the applicable Appendices, Paragraphs I-1021 through X-1021 and Tables I-1021 through X-1021. The written procedure shall establish a single value, or range of values, for each requirement.

7. TESTING

The role of the ASME Committee responsible for developing and maintaining the ASME BPVC is to establish rules of safety that relate only to pressure boundary integrity. To support this objective, the ASME BPVC provides pressure testing requirements for boilers and pressure vessels, and alternative pressure testing and proof testing requirements for pressure vessels.

The primary purpose for pressure testing is to confirm that the boiler or pressure vessel has been properly constructed and that it has a significant design margin above and beyond its nominal operating pressure. In this sense, the pressure test is seen to demonstrate the validity of the design as a pressure container [14]. A pressure test also serves as a leak test. Any leak revealed by the pressure test except for leakage that might occur at temporary test closures must be repaired, and then the boiler or pressure vessel must be retested.

7.1 PRESSURE TESTING

Pressure tests of boilers and pressure vessels constructed in accordance with ASME BPVC rules are performed after fabrication is completed primarily to verify the leak tight integrity of the pressure boundary. These pressure tests are also performed to identify gross deformations or anomalies that may indicate design errors, material deficiencies, or weld defects. A successful pressure testing of a boiler or pressure vessel is required before the Authorized Inspector will approve application of the Certification Mark by the Manufacturer.

Hydrostatic and pneumatic pressure tests are not intended to verify the pressure-resisting (burst) capacity of a pressure vessel because the ASME BPVC does not provide methods for determining burst pressure other than by proof testing which involves a burst test as discussed in Sect. 7.3.2.2 of this report. This conclusion is reinforced by the fact that the specified minimum hydrostatic and pneumatic test pressures are not the same within a Construction Code and they vary from one Construction Code to another and, sometime, from one Construction Code edition to another. In addition, the specified minimum hydrostatic test pressure is greater than the minimum pneumatic test pressure in the same Construction Code edition.

Section I and Section VIII, Division 2 of the ASME BPVC specify limits for maximum primary stresses that occur during pressure testing. These primary stress limits are intended to ensure that the boiler or pressure vessel remains below the plastic collapse stress limit. Corresponding stress limits are not specified in Section VIII, Division 1 for hydrostatic and pneumatic tests. Instead, any visible permanent distortion that occurs during pressure testing could result in rejection of the pressure vessel by the Inspector.

Hydrostatic and pneumatic pressure tests are not intended to blunt cracks where crack tip blunting is the phenomenon of small-scale plastic deformation of an initially sharp crack. Crack tip blunting only occurs when the actual stress is high enough to produce plastic deformation in the material at the crack tip. This stress state is related to the temperature, actual yield strength, and strain hardening properties of the material.

7.1.1 Basis for Pressure Testing Limits in Section I of the ASME BPVC

The objective of design rules specified in Section I of the ASME BPVC is to establish the wall thickness of a boiler so that the membrane stress, P_m, does not exceed the maximum allowable stress of the material. However, in no case can the maximum allowable membrane stress be greater than two-third of the minimum specified yield strength, $P_m \leq 2/3\ S_y$, of the material. Allowable membrane stresses must be:

- applicable to the ferrous and nonferrous materials permitted for boilers construction in accordance rules specified in Section I of the ASME BPVC, and
- consistent with criteria provided in Paragraphs 1-100*(a)(3)* and 1-100*(a)(4*) in Mandatory Appendix 1 – Basis for Establishing Stress Values in Tables 1A and 1B in Section II, Part D of the ASME BPVC.

Boiler designs that do not exceed allowable stress limits ensure a minimum design margin against plastic collapse equal to or greater than 1.5. Additional discussion about allowable stress limits specified in Mandatory Appendix 1 in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC is presented in Sect. 4.4.1 of this report.

7.1.1.1 ASME BPVC, Section I – Hydrostatic Pressure Testing Requirements for Boilers

Hydrostatic pressure testing requirements for boilers are provided in Paragraph PG-99 in the 2007 and 2021 editions of Section I of the ASME BPVC. A synopsis of pressure testing requirements provided in these two editions is presented in Table 7.1 of this report.

Table 7.1 Synopsis of hydrostatic pressure testing requirements for boilers provided in the 2007 and 2021 editions of Section I of the ASME BPVC

Hydrostatic Pressure Test Requirements for Boilers – Section I	
2007 edition	**2021 edition**
Paragraph PG-99 states: Hydrostatic testing of the completed boiler unit shall be conducted in accordance with the following requirements: After a boiler has been completed (see PG-104), it shall be subjected to pressure tests using water at not less than ambient temperature, but in no case less than 70°F (20°C). Where required test pressures are specified in this paragraph, whether minimum or maximum pressures, they apply to the highest point of the boiler system. When the boiler is completed in the Manufacturer's shop without boiler external piping, subsequent hydrostatic testing of the boiler external piping shall be the responsibility of any holder of a valid "S," "A," or "PP" stamp. The safety valves need not be included in the hydrostatic test. The tests shall be made in two stages in the following sequence:	**Paragraph PG-99** states: Hydrostatic testing of the completed boiler unit shall be conducted in accordance with the following requirements: After a boiler has been completed (see PG-104), it shall be subjected to pressure tests using water at not less than ambient temperature, but in no case less than 70°F (20°C). Where required test pressures are specified in this paragraph, whether minimum or maximum pressures, they apply to the highest point of the boiler system. When the boiler is completed in the Manufacturer's shop without boiler external piping, subsequent hydrostatic testing of the boiler external piping shall be the responsibility of any holder of a valid Certification Mark with the "S," "A," or "PP" Designator. The pressure relief valves need not be included in the hydrostatic test. The tests shall be made in two stages in the following sequence:
Paragraph PG-99.1 states: Hydrostatic pressure tests shall be applied by raising the pressure gradually to not less than 1-1/2 times the maximum allowable working pressure as shown on the data report to be stamped on the boiler. No part of the boiler shall be subjected to a general membrane stress greater than 90% of its yield strength (0.2% offset) at test temperature. The primary membrane stress to	**Paragraph PG-99.1** states: Hydrostatic pressure tests shall be applied by raising the pressure gradually to not less than 1-1/2 times the maximum allowable working pressure as shown on the data report to be stamped on the boiler. No part of the boiler shall be subjected to a general membrane stress greater than 90% of its yield strength (0.2% offset) at test temperature. The primary membrane stress to

Hydrostatic Pressure Test Requirements for Boilers – Section I	
2007 edition	**2021 edition**
which boiler components are subjected during hydrostatic test shall be taken into account when designing the components. Close visual inspection for leakage is not required during this stage.	which boiler components are subjected during hydrostatic test shall be taken into account when designing the components. Close visual examination for leakage is not required during this stage.
Paragraph PG-99.2 states: The hydrostatic test pressure may then be reduced to the maximum allowable working pressure, as shown on the Data Report, to be stamped on the boiler and maintained at this pressure while the boiler is carefully examined. The metal temperature shall not exceed 120°F (50°C) during the close examination.	**Paragraph PG-99.2** states: The hydrostatic test pressure may then be reduced to the maximum allowable working pressure, as shown on the Data Report, to be stamped on the boiler and maintained at this pressure while the boiler is carefully examined. The metal temperature shall not exceed 120°F (50°C) during the close visual examination.
Paragraph PG-99.3 states: A completed forced-flow steam generator with no fixed steam and waterline, having pressure parts designed for different pressure levels along the path of water-steam flow, shall be subjected to a hydrostatic pressure test by the above procedure (PG-99.1 and PG-99.2)	**Paragraph PG-99.3** states: A completed forced-flow steam generator with no fixed steam and waterline, having pressure parts designed for different pressure levels along the path of water-steam flow, shall be subjected to a hydrostatic pressure test by the above procedure (PG-99.1 and PG-99.2) based upon
PG-99.3.1 For the first stage test (PG-99.1) a hydrostatic test pressure of not less than 1-1⁄2 times the maximum allowable working pressure at the superheater outlet as shown in the master stamping (PG-106.3) but no less than 1-1⁄4 times the maximum allowable working pressure of any part of the boiler, excluding the boiler external piping.	**PG-99.3.1** For the first stage test (PG-99.1) a hydrostatic test pressure of not less than 1-1/2 times the maximum allowable working pressure at the superheater outlet as shown in the master stamping (PG-106.3) but no less than 1-1/4 times the maximum allowable working pressure of any part of the boiler, excluding the boiler external piping.
PG-99.3.2 For the second stage test (PG-99.2) the hydrostatic test pressure may be reduced to not less than the maximum allowable working pressure at the superheater outlet.	**PG-99.3.2** For the second stage test (PG-99.2) the hydrostatic test pressure may be reduced to not less than the maximum allowable working pressure at the superheater outlet.

These rules state that the maximum member stress, P_m, of the material used to construct the boiler must not exceed two-thirds of the minimum specified yield strength, $P_m \leq 2/3\ S_y$, of the material, and according to rules specified in Paragraph PG-99.1, the minimum hydrostatic test pressure, P_T, must be equal to or greater than 1.5 MAWP (i.e., $P_T \geq 1.5$ MAWP). Paragraph PG-99.1 further states that no part of the boiler may be subjected to a general membrane stress greater than 90% of its yield strength, $P_m \leq 0.90\ S_y$, at the test temperature.

Figure 7.1 of this report compares the maximum allowable design stress and hydrostatic pressure testing limits specified in Paragraph PG-99 in the 2007 and 2021 editions of Section I of the ASME BPVC to plastic collapse stress limit discussed in Sect. 4.8.1 of this report. Note that the hydrostatic pressure testing stress limit in this figure corresponds to a MAWP that is based on a maximum allowable design stress limit equal to $2/3\ S_y$.

It is important to note that:

- Based on the side-by-side comparation shown in Table 7.1, hydrostatic pressure testing rules specified in Paragraph PG-99 in the 2007 and 2021 editions of Section I of the ASME BPVC are the same from an equivalent safety viewpoint.

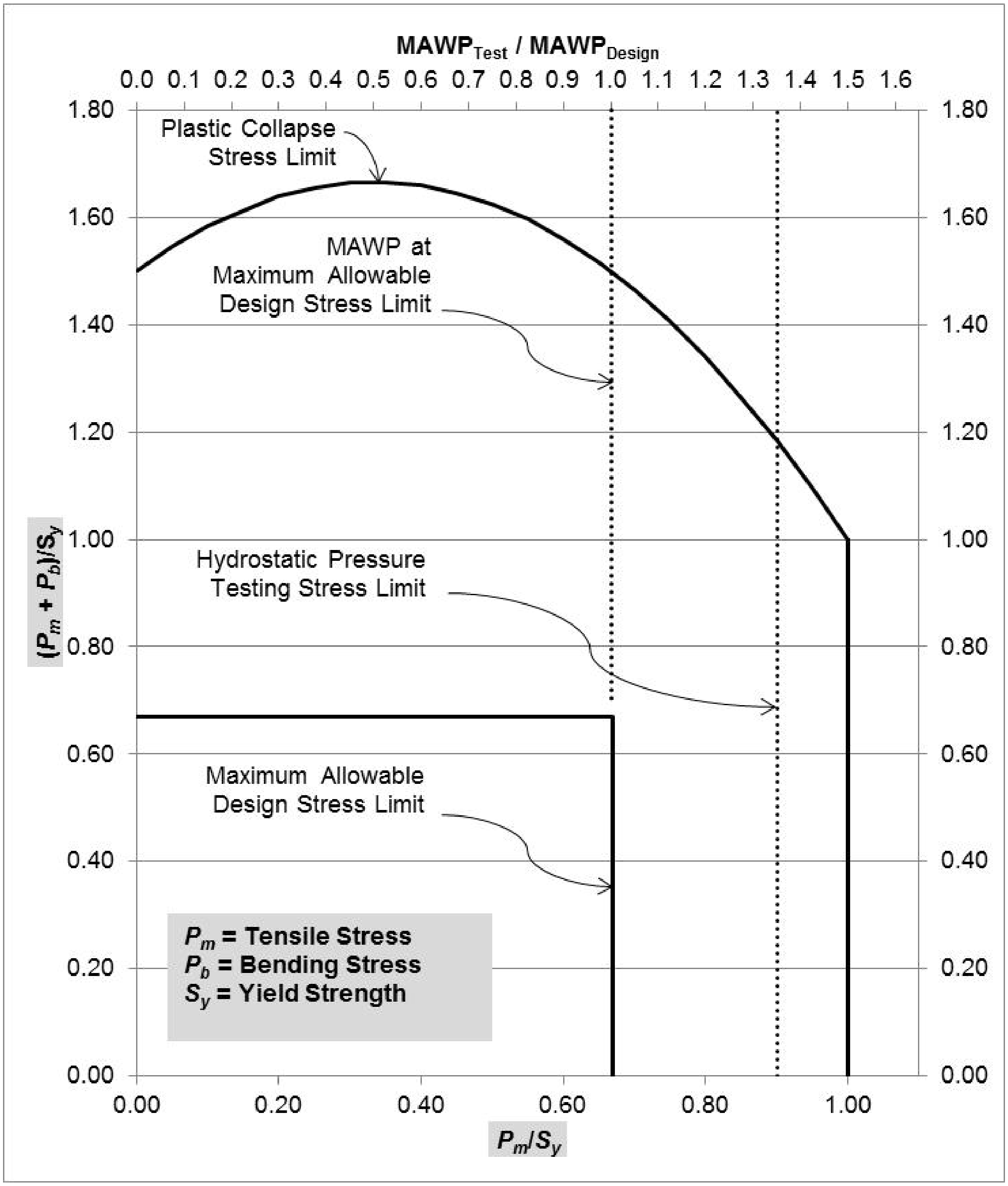

Fig. 7.1 Comparison of maximum allowable design stress and hydrostatic pressure testing limits specified in the 2007 and 2021 editions of Section I of the ASME BPVC to the plastic collapse stress limit

- To avoid yielding during hydrostatic pressure testing, the primary membrane stress limit of $0.90S_y$ specified in Paragraph PG-99.1 in the 2007 and 2021 editions of Section I of the ASME BPVC ensures compliance with the principles of limit design theory, but this limit conflicts with the test pressure rule, $P_T \geq 1.5$ MAWP (minimum), when the MAWP is based on an allowable primary membrane stress, P_m, equal to $2/3\ S_y$. Under these conditions, the primary membrane stress limit establishes a maximum hydrostatic test pressure equal to 1.35 MAWP (i.e., 0.90×1.5 MAWP). Consequently, the primary membrane design stress used to determine MAWP must be reduced to a value less than $2/3\ S_y$ to satisfy the minimum required test pressure of 1.5 MAWP and maintain a primary membrane stress, P_m, below the primary membrane stress limit of $0.90S_y$. As an example, if the hydrostatic test pressure, P_T, equals 1.5 MAWP and the primary membrane stress at the test pressure equal $0.90S_y$, then the allowable primary membrane stress, P_m, used to establish MAWP must be equal to $0.60S_y$ or less (i.e., $P_m = 0.9S_y/1.5$).

- As discussed in Sect. 8.1 of this report, overpressure protection rules specified in Paragraph PG-67.4.2 in the 2007 and 2021 editions of Section I of the ASME BPVC limit the pressure of an operating boiler, except for the steam piping between the boiler and the prime mover, to 1.20 MAWP or less. This overpressure protection limit ensures that the primary membrane stress, P_m, does not exceed $0.80S_y$. (i.e., $1.20/1.50$). A minimum hydrostatic test pressure equal to the lesser of 1.5 MAWP or a membrane stress, P_m, no greater than $0.90S_y$ ensures that the boiler will never experience a maximum overpressure while in service that is greater than the hydrostatic test pressure (i.e., 0.90×1.5 MAWP > 1.20 MAWP).
- Rules in the 2007 and 2021 editions of Section I of the ASME BPVC do not specify a minimum or maximum hydrostatic test pressure duration nor do they require compliance with rules for leak testing specified in Section V, Article 10. However, rules specified in Section I state that a boiler must be maintained at the MAWP while the boiler is carefully examined.
- The rules specified in Paragraph PG-99 in the 2021 edition of Section I of the ASME BPVC do not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC.

7.1.1.2 ASME BPVC, Section I – Pneumatic Pressure Testing Requirements for Boilers

The 2007 and 2021 editions of Section I of the ASME BPVC do not specify rules for pneumatic pressure testing of boilers.

7.1.2 Basis for Pressure Testing Limits in Section VIII, Division 1 of the ASME BPVC

The objective of design rules specified in Section VIII, Division 1 of the ASME BPVC is to establish the wall thickness of a pressure vessel so that the primary membrane stress, P_m, does not exceed two-thirds of the minimum specified yield strength (i.e., $P_m \leq 2/3\ S_y$) of the material. In addition, Paragraph UG-23*(c)* in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC states that a combined maximum primary membrane stress plus primary bending stress, $P_m + P_b$, across the wall thickness cannot exceed 1.5 time the maximum allowable stress in tension (i.e., $P_m + P_b \leq 1.0\ S_y$). Further discussions about allowable design stresses specified in Section VIII, Division 1 of the ASME BPVC is presented in Sect. 4.4.1 of this report.

7.1.2.1 ASME BPVC, Section VIII, Division 1 – Hydrostatic Pressure Testing Requirements for Pressure Vessels

Hydrostatic pressure testing requirements for pressure vessels are specified in Paragraph UG-99 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. A synopsis of pressure testing rules from these two editions is presented in Table 7.2 of this report.

Table 7.2 Synopsis of hydrostatic pressure testing requirements for pressure vessels specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC

Hydrostatic Pressure Test Requirements for Pressure Vessels – Section VIII, Division 1	
2007 Edition	**2021 Edition**
Paragraph UG-99*(b)* states: *(b)* Except as otherwise permitted in *(a)* above and 27-4, vessels designed for internal pressure shall be subjected to a hydrostatic test pressure which at every point in the vessel is at least equal to 1.3 times the maximum allowable working pressure to be marked on the vessel multiplied by the lowest ratio (for the materials of which the vessel is constructed) of the stress value S for the test temperature on the vessel to the stress value S for the design temperature (see UG-21). All loadings that may exist during this test shall be given consideration.	**Paragraph UG-99*(b)*** states: *(b)* Except as otherwise permitted in (a) above and 27-4, vessels designed for internal pressure shall be subjected to a hydrostatic test pressure that at every point in the vessel is at least equal to 1.3 times the maximum allowable working pressure multiplied by the lowest stress ratio (LSR) for the pressure-boundary materials of which the vessel is constructed. The stress ratio for each pressure-boundary material is the ratio of the stress value S at its test temperature to the stress value S at its design temperature (see UG-21). Bolting shall not be included in the determination of the LSR, except when 1.3 times the LSR multiplied by the allowable stress of the bolt at its design temperature exceeds 90% of the bolt material specified minimum yield strength at the test temperature. All loadings that may exist during this test shall be given consideration. The hydrostatic test pressure reading shall be adjusted to account for any static head conditions depending on the difference in elevation between the chamber being tested and the pressure gauge.
Paragraph UG-99*(c)* states: *(c)* A hydrostatic test based on a calculated pressure may be used by agreement between the user and the Manufacturer. The hydrostatic test pressure at the top of the vessel shall be the minimum of the test pressures calculated by multiplying the basis for calculated test pressure as defined in 3-2 for each pressure element by 1.3 and reducing this value by the hydrostatic head on that element. When this pressure is used, the Inspector shall reserve the right to require the Manufacturer or the designer to furnish the calculations used for determining the hydrostatic test pressure for any part of the vessel.	**Paragraph UG-99*(c)*** states: *(c)* A hydrostatic test based on a calculated pressure may be used by agreement between the user and the Manufacturer. The hydrostatic test pressure at the top of the vessel shall be the minimum of the test pressures calculated by multiplying the basis for calculated test pressure as defined in 3-2 for each pressure element by 1.3 and reducing this value by the hydrostatic head on that element. When this pressure is used, the Inspector shall reserve the right to require the Manufacturer or the designer to furnish the calculations used for determining the hydrostatic test pressure for any part of the vessel.
Paragraph UG-99*(d)* states: *(d)* The requirements of *(b)* above represent the minimum standard hydrostatic test pressure required by this Division. The requirements of *(c)* above represent a special test based on calculations. Any intermediate value of pressure may be used. This Division does not specify an upper limit for hydrostatic test pressure. However, if the hydrostatic test pressure is allowed to exceed, either intentionally or accidentally, the value determined as prescribed in *(c)* above to the degree that the vessel is subjected to visible permanent distortion, the Inspector shall reserve the right to reject the vessel.	**Paragraph UG-99*(d)*** states: *(d)* The requirements of *(b)* above represent the minimum standard hydrostatic test pressure required by this Division. The requirements of *(c)* above represent a special test based on calculations. Any intermediate value of pressure may be used. This Division does not specify an upper limit for hydrostatic test pressure. However, if the hydrostatic test pressure is allowed to exceed, either intentionally or accidentally, the value determined as prescribed in *(c)* above to the degree that the vessel is subjected to visible permanent distortion, the Inspector shall reserve the right to reject the vessel.
Paragraph UG-99*(e)* states:	**Paragraph UG-99*(e)*** states:

Hydrostatic Pressure Test Requirements for Pressure Vessels – Section VIII, Division 1	
2007 Edition	**2021 Edition**
(e) Combination units [see UG-19*(a)* and UG-21] shall be tested by one of the following methods.	*(e)* Combination units [see UG-19*(a)* and UG-21] shall be tested by one of the following methods. Common elements of chambers that are otherwise exempted per U-1*(c)(2)(-f)* or U-1*(c)(2)(-g)* shall be pressure tested in accordance with *(1)* or *(2)* below.
(1) Pressure chambers of combination units that have been designed to operate independently shall be hydrostatically tested as separate vessels, that is, each chamber shall be tested without pressure in the adjacent chamber. If the common elements of a combination unit are designed for a larger differential pressure than the higher maximum allowable working pressure to be marked on the adjacent chambers, the hydrostatic test shall subject the common elements to at least their design differential pressure, corrected for temperature as in *(b)* above, as well as meet the requirements of *(b)* or *(c)* above for each independent chamber.	*(1) Independent Pressure Chambers*. Pressure chambers of combination units that have been designed to operate independently shall be hydrostatically tested as separate vessels, that is, each chamber shall be tested without pressure in the adjacent chamber. If the common elements of a combination unit are designed for a larger differential pressure than the higher maximum allowable working pressure to be marked on the adjacent chambers, the hydrostatic test shall subject the common elements to at least their design differential pressure times the LSR as in *(b)* above for the common elements as well as meet the requirements of *(b)* or *(c)* above for each independent chamber.
(2) When pressure chambers of combination units have their common elements designed for the maximum differential pressure that can possibly occur during startup, operation, and shutdown, and the differential pressure is less than the higher pressure in the adjacent chambers, the common elements shall be subjected to a hydrostatic test pressure of at least 1.3 times the differential pressure to be marked on the unit, corrected for temperature as in UG-99*(b)*. Following the test of the common elements and their inspection as required by *(g)* below, the adjacent chambers shall be hydrostatically tested simultaneously [see *(b)* or *(c)* above]. Care must be taken to limit the differential pressure between the chambers to the pressure used when testing the common elements. The vessel stamping and the vessel Data Report must describe the common elements and their limiting differential pressure. See UG-116*(j)* and UG-120*(b)*.	*(2) Dependent Pressure Chambers*. When pressure chambers of combination units have their common elements designed for the maximum differential pressure that can possibly occur during startup, operation, and shutdown, and the differential pressure is less than the higher pressure in the adjacent chambers, the common elements shall be subjected to a hydrostatic test pressure of at least 1.3 times the differential pressure to be marked on the unit times the LSR as in *(b)* above for the common elements. Following the test of the common elements and their inspection as required by *(g)* below, the adjacent chambers shall be hydrostatically tested simultaneously [see *(b)* or *(c)* above]. Care must be taken to limit the differential pressure between the chambers to the pressure used when testing the common elements. The vessel stamping and the vessel Data Report must describe the common elements and their limiting differential pressure. See UG-116*(j)* and UG-120*(b)*.
Paragraph UG-99*(f)* states:	**Paragraph UG-99*(f)*** states:
(f) Single-wall vessels designed for a vacuum or partial vacuum only, and chambers of multichamber vessels designed for a vacuum or partial vacuum only, shall be subjected to an internal hydrostatic test or when a hydrostatic test is not practicable, to a pneumatic test in accordance with the provisions of UG-100. Either type of test shall be made at a pressure not less than 1.3 times the difference between normal atmospheric pressure and the minimum design internal absolute pressure.	*(f)* Single-wall vessels and individual pressure chambers of combination units designed for vacuum only (MAWP) less than or equal to zero) shall be subjected to either *(1)* an internal hydrostatic pressure test in accordance with UG-99, or a pneumatic pressure test in accordance with UG-100. The applied test pressure shall be not less than 1.3 times the specified external design pressure; or *(2)* a vacuum test conducted at the lowest value of specified absolute internal design pressure. In conjunction with the vacuum test, a leak test shall be

Hydrostatic Pressure Test Requirements for Pressure Vessels – Section VIII, Division 1	
2007 Edition	**2021 Edition**
	performed following a written procedure complying with the applicable technical requirements of Section V, Article 10 for the leak test method and technique specified by the user. Leak testing personnel shall be qualified and certified as required by Section V, Article 1, T-120*(e)*. (See Sect. 6.3.1 of this report.)
Paragraph UG-99*(g)* states: *(g)* Following the application of the hydrostatic test pressure, an inspection shall be made of all joints and connections. This inspection shall be made at a pressure not less than the test pressure divided by 1.3. Except for leakage that might occur at temporary test closures for those openings intended for welded connections, leakage is not allowed at the time of the required visual inspection. Leakage from temporary seals shall be directed away so as to avoid masking leaks from other joints. The visual inspection of joints and connections for leaks at the test pressure divided by 1.3 may be waived provided: *(1)* a suitable gas leak test is applied; *(2)* substitution of the gas leak test is by agreement reached between Manufacturer and Inspector; *(3)* all welded seams which will be hidden by assembly be given a visual examination for workmanship prior to assembly; *(4)* the vessel will not contain a “lethal” substance.	**Paragraph UG-99*(g)*** states: *(g)* Following the application of the hydrostatic test pressure, an inspection shall be made of all joints and connections. This inspection shall be made at a pressure not less than the test pressure divided by 1.3. Except for leakage that might occur at temporary test closures for those openings intended for welded connections, leakage is not allowed at the time of the required visual inspection. Leakage from temporary seals shall be directed away so as to avoid masking leaks from other joints. The visual inspection of joints and connections for leaks at the test pressure divided by 1.3 may be waived, provided: *(1)* a suitable gas leak test is applied; *(2)* substitution of the gas leak test is by agreement reached between Manufacturer and Inspector; *(3)* all welded seams that will be hidden by assembly are given a visual examination for workmanship prior to assembly; *(4)* the vessel will not contain a “lethal” substance.
Paragraph UG-99*(k)* states: *(k)* Vessels, except for those in lethal service, may be painted or otherwise coated either internally or externally, and may be lined internally, prior to the pressure test. However, the user is cautioned that such painting / coating /lining may mask leaks that would otherwise have been detected during the pressure test.	**Paragraph UG-99*(k)*** states: *(k) Painting and Coating* *(1)* Unless permitted by the user or his designated agent, pressure-retaining welds of vessels shall not be painted or otherwise coated either internally or externally prior to the pressure test. [See UCI-99*(b)* and UCD-99*(b)*.] *(2)* When painting or coating prior to the hydrostatic test is permitted, or when internal nonmetallic linings are to be applied, the pressure-retaining welds shall first be leak tested in accordance with Section V, Article 10. Such a test may be waived with the approval of the user or his designated agent. *(3)* Vessels for lethal service [see UW-2*(a)*] *(-a)* shall not be painted or coated either internally or externally prior to the hydrostatic pressure test *(-b)* shall not be internally lined by mechanical or welded attachments prior to the hydrostatic pressure test unless the requirements of UCL-51 are followed *(4)* The requirements given in *(1)* and *(2)* do not apply to glass-lined vessels; see 27-4.

Based on the side-by-side comparation shown in Table 7.2, hydrostatic pressure testing rules specified in Paragraph UG-99 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC are not the same. The differences are discussed below.

Paragraph UG-99*(b)*

Hydrostatic testing rules specified in Paragraph UG-99*(b)* in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC state that the minimum hydrostatic test pressure, P_T, is equal to or greater than 1.3 MAWP times the LSR for the materials of which the pressure vessel is constructed. These rules state that the minimum hydrostatic test pressure shall be calculated using the following equation.

$$P_T = 1.3 \text{ MAWP} \left(\frac{S_T}{S}\right)$$

However, Paragraph UG-99*(b)* in the 2021 edition of Section VIII, Division 1 of the ASME BPVC provides additional considerations that could affect the magnitude of the minimum hydrostatic test pressure. These additional considerations include the following.

- Bolting shall not be included in the determination of the LSR, except when 1.3 times the LSR multiplied by the allowable stress of the bolt at its design temperature exceeds 90% of the bolt material specified minimum yield strength at the test temperature.
- The hydrostatic test pressure reading shall be adjusted to account for any static head conditions depending on the difference in elevation between the chamber being tested and the pressure gauge.

Paragraph UG-99*(f)*

Paragraph UG-99*(f)* in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC permits an internal hydrostatic or pneumatic pressure test of single-wall vessels and individual pressure chambers of combination units designed for vacuum only (MAWP less than or equal to zero). Either type of test shall be made at a pressure not less than 1.3 times the difference between normal atmospheric pressure and the minimum design internal absolute pressure.

Paragraph UG-99*(f)(2)* in the 2021 edition also includes alternative rules for single-wall vessels and individual pressure chambers of combination units designed for vacuum only (MAWP less than or equal to zero). These alternative rules state that in conjunction with the vacuum test, a leak test shall be performed following a written procedure complying with the applicable technical requirements of Section V, Article 10 for the leak test method and technique specified by the user. Paragraph UG-99*(f)* in the 2021 edition further states that leak testing personnel shall be qualified and certified as required by Section V, Article 1, T-120*(e)*. Leak testing requirements prescribed in Section V, Article 10 are discussed in Sect. 6.4 of this report.

Paragraph UG-99*(k)*

Rules specified in Paragraph UG-99*(k)* in the 2007 edition of Section VIII, Division 1 of the ASME BPVC for painted and coated pressure vessel were revised and expanded in the 2021 edition. Paragraph UG-99*(k)* in the 2021 edition specifies conditions where pressure-retaining welds must remain uncoated or unpainted prior to pressure testing and when pressure-retaining welds must first be leak tested in accordance with Section V, Article 10.

Figure 7.2 of this report compares the maximum allowable design stress and hydrostatic pressure testing specified in Paragraph UG-99 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC to plastic collapse stress limit discussed in Sect. 4.8.1 of this report. Note that the minimum

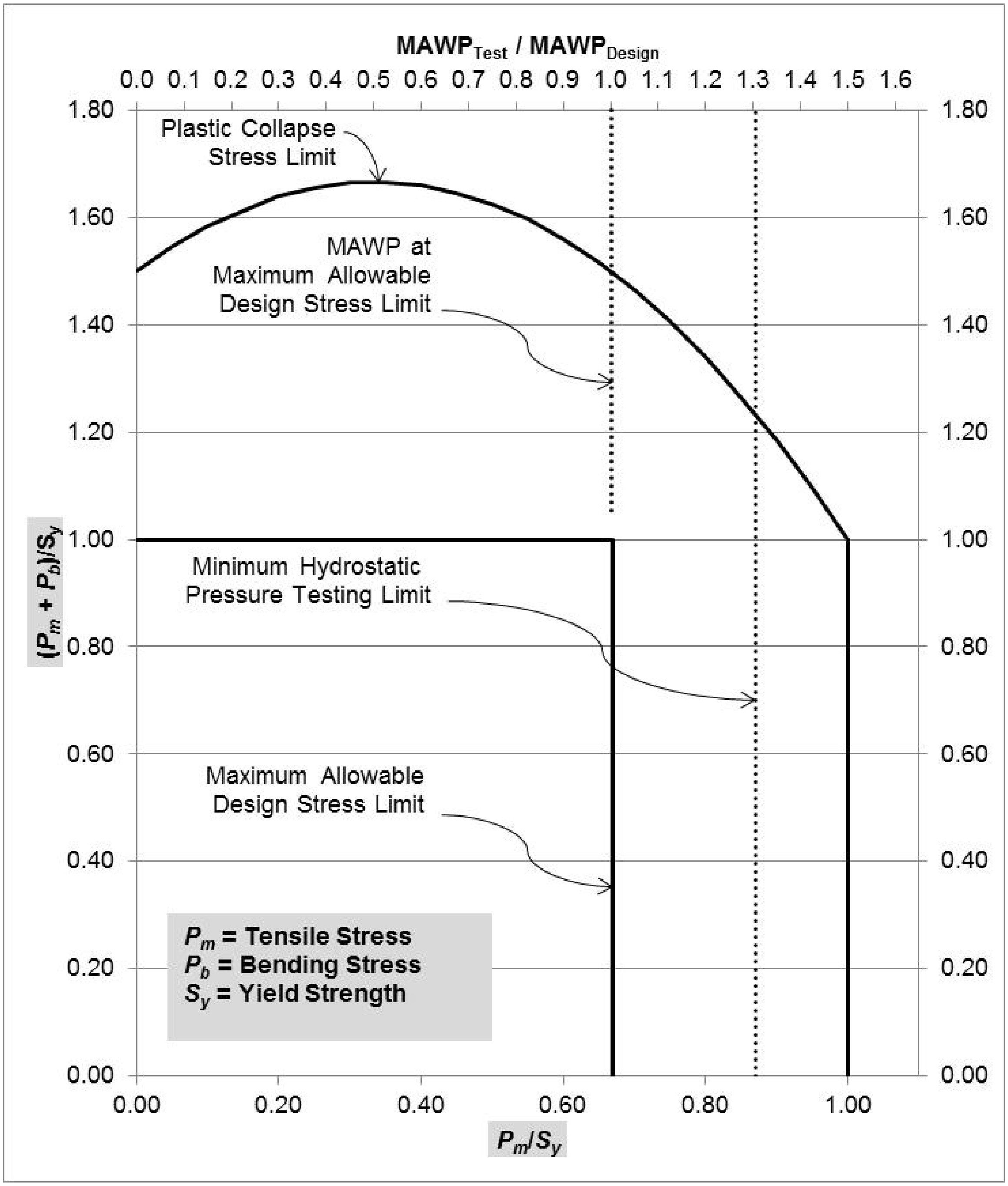

Fig. 7.2 Comparison of maximum allowable design stress and hydrostatic pressure testing limits specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC to plastic collapse stress limit

hydrostatic pressure testing limit shown in this figure corresponds to a MAWP that is based on a maximum allowable design stress equal to $2/3\ S_y$.

It is also important to note that:

- The calculated test pressure, P_T, is defined in Mandatory Appendix 3 – Definitions, Paragraph 3-2 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC.

This definition states that the requirements for determining the test pressure based on calculations are outlined in UG-99*(c)* for the hydrostatic test and in UG-100*(b)* for the pneumatic test. The basis for calculated test pressure in either of these paragraphs is the highest permissible internal pressure as determined by the design formulas, for each element of the vessel using nominal thicknesses with corrosion allowances included and using the allowable stress values given in Section II, Part D, Tables 1A and 1B, as applicable, of the ASME BPVC for the temperature of the test (See Sect. 4.4.1 of the report).

- Rules specified in Paragraph UG-99*(c)* further states that if the hydrostatic test pressure is allowed to exceed, either intentionally or accidentally, the value determined by calculation as prescribed in Paragraph UG-99*(c)* to the degree that the vessel is subjected to visible permanent distortion, the Inspector reserves the right to reject the pressure vessel.
- Hydrostatic test pressure rules specified in Paragraph UG-99*(b)* in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC allow the primary membrane stress to exceed the plastic collapse stress limit when MAWP is based on an allowable primary membrane stress, P_m, equal to $2/3\ S_y$ and the hydrostatic test pressure is greater than 1.5 MAWP. This hydrostatic pressure test condition violates the principles of limit design theory discussed in Sect. 4.6 of this report and could result in visible permanent distortion of the pressure vessel sufficient for the Inspector to reject the vessel.
- Overpressure protection rules specified in Paragraph UG-133*(b)* – Determination of Pressure Relieving Requirements in the 2007 edition and Paragraph UG-153*(a)(2)* – Overpressure Limits in the 2021 edition of Section VIII, Division 1 of the ASME BPVC state that when a pressure vessel can be exposed to fire or other unexpected sources of external heat, the pressure relief device(s) must be capable of preventing the pressure from rising more than 21% above the MAWP. (i.e., 1.21 MAWP). This overpressure protection limit ensures that the primary membrane stress, P_m, does not exceed $0.81\ S_y$ (i.e., $1.21/1.50$) under fire conditions. A minimum hydrostatic test pressure equal to 1.3 MAWP ensures that the pressure vessel will never experience a maximum overpressure while in service that is greater than the hydrostatic test pressure (i.e., 1.3 MAWP > 1.21 MAWP).
- Rule in Paragraph UG-99 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC do not specify a minimum or maximum hydrostatic test pressure duration.
- Although the additional rules specified in Paragraph UG-99 in the 2021 edition of Section VIII, Division 1 of the ASME BPVC expand the scope of hydrostatic testing requirements provided in the 2007 edition, they do not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC.

7.1.2.2 ASME BPVC, Section VIII, Division 1 – Pneumatic Pressure Testing Requirements for Pressure Vessels

Pneumatic pressure testing requirements for pressure vessels are specified in Paragraph UG-100 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. A synopsis of pneumatic pressure testing rules from these two editions is presented in Table 7.3 of this report.

Table 7.3 Synopsis of pneumatic pressure testing requirements for pressure vessels specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC

Pneumatic Pressure Test Requirements for Pressure Vessels – Section VIII, Division 1	
2007 Edition	**2021 Edition**
Paragraph UG-100(*a*) states: A pneumatic test prescribed in this Paragraph may be used in lieu of the standard hydrostatic test prescribed in UG-99 for vessels: 1. that are so designed and/or supported that they cannot safely be filled with water. 2. not readily dried, that are to be used in services where traces of the testing liquid cannot be tolerated and the parts of which have, where possible, been previously tested by hydrostatic pressure to the pressure required in Paragraph UG 99.	**Paragraph UG-100(*a*)** states: A pneumatic test prescribed in this paragraph may be used in lieu of the standard hydrostatic test prescribed in UG-99 for vessels: *(1)* that are so designed and/or supported that they cannot safely be filled with water. *(2)* not readily dried, that are to be used in services where traces of the testing liquid cannot be tolerated and the parts of which have, where possible, been previously tested by hydrostatic pressure to the pressure required in UG-99.
Paragraph UG-100(*b*) states: *(b)* Except for enameled vessels, for which the pneumatic test pressure shall be at least equal to, but need not exceed, the maximum allowable working pressure to be marked on the vessel, the pneumatic test pressure shall be at least equal to 1.1 times the maximum allowable working pressure to be stamped on the vessel multiplied by the lowest ratio (for the materials of which the vessel is constructed) of the stress value *S* for the test temperature of the vessel to the stress value *S* for the design temperature (see UG-21). In no case shall the pneumatic test pressure exceed 1.1 times the basis for calculated test pressure as defined in 3-2.	**Paragraph UG-100(*b*)** states: *(b)* Except for enameled vessels, for which the pneumatic test shall be at least equal to, but need not exceed, the maximum allowable working pressure to be marked on the vessel, the pneumatic test pressure at every point in the vessel shall be at least equal to 1.1 times the maximum allowable working pressure multiplied by the lowest stress ratio (LSR) for the pressure-boundary materials of which the vessel is constructed. The stress ratio for each pressure-boundary material is the ratio of the stress value *S* at its test temperature to the stress value *S* at its design temperature (see UG-21). Bolting shall not be included in the determination of the LSR, except when 1.1 times the LSR multiplied by the allowable stress of the bolt at its design temperature exceeds 90% of the bolt material specified minimum yield strength at the test temperature. All loadings that may exist during this test shall be given consideration. In no case shall the pneumatic test pressure exceed 1.1 times the basis for the calculated test pressure as defined in 3-2.
Paragraph UG-100*(c)* states: *(c)* The metal temperature during pneumatic test shall be maintained at least 30°F (17°C) above the minimum design metal temperature to minimize the risk of brittle fracture. [See UG-20 and General Note (6) to Fig. UCS-66.2.]	**Paragraph UG-100*(c)*** states: *(c)* The metal temperature during pneumatic test shall be maintained at least 30°F (17°C) above the minimum design metal temperature to minimize the risk of brittle fracture. [See UG-20 and Figure UCS-66.2, Note (6).]
Paragraph UG-100*(d)* states: *(d)* The pressure in the vessel shall be gradually increased to not more than one-half of the test pressure. Thereafter, the test pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached. Then the pressure shall be reduced to a value equal to the test pressure divided by 1.1 and held for a sufficient time to permit inspection of the vessel. Except for leakage that	**Paragraph UG-100(*d*)** states: *(d)* Combination units [see UG-19*(a)* and UG-21] shall be tested by one of the following methods. Common elements of chambers that are otherwise exempted per U-1*(c)(2)(-f)* and U-1*(c)(2)(-g)* shall be pressure tested in accordance with *(1)* or *(2)*. *(1) Independent Pressure Chambers.* Pressure chambers of combination units that have been designed to operate independently shall be pneumatically tested

Pneumatic Pressure Test Requirements for Pressure Vessels – Section VIII, Division 1	
2007 Edition	**2021 Edition**
might occur at temporary test closures for those openings intended for welded connections, leakage is not allowed at the time of the required visual inspection. Leakage from temporary seals shall be directed away so as to avoid masking leaks from other joints. The visual inspection of the vessel at the required test pressure divided by 1.1 may be waived provided: *(1)* a suitable gas leak test is applied; *(2)* substitution of the gas leak test is by agreement reached between Manufacturer and Inspector; *(3)* all welded seams which will be hidden by assembly be given a visual examination for workmanship prior to assembly; *(4)* the vessel will not contain a "lethal" substance.	as separate vessels, which means that each chamber shall be tested without pressure in the adjacent chamber. If the common elements of a combination unit are designed for a larger differential pressure than the higher maximum allowable working pressure to be marked on the adjacent chambers, the pneumatic test shall subject the common elements to at least their design differential pressure, corrected for temperature as in *(b)*, as well as meet the requirements of *(b)* for each independent chamber. *(2) Dependent Pressure Chambers.* When pressure chambers of combination units have their common elements designed for the maximum differential pressure that can possibly occur during startup, operation, and shutdown, and the differential pressure is less than the higher pressure in the adjacent chambers, the common elements shall be subjected to a pneumatic test pressure of at least 1.1 times the differential pressure to be marked on the unit, corrected for temperature as in *(b)*. Following the test of the common elements and their inspection as required by *(e)*, the adjacent chambers shall be pneumatically tested simultaneously [see (b)]. Care must be taken to limit the differential pressure between the chambers to the pressure used when testing the common elements. The vessel stamping and the vessel Data Report must describe the common elements and their limiting differential pressure. See UG-116*(j)* and UG-120*(b)*.
See Paragraph UG-100*(e)* below.	**Paragraph UG-100*(e)*** states: *(e)* The pressure in the vessel shall be gradually increased to not more than one-half of the test pressure. Thereafter, the test pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached. Then the pressure shall be reduced to a value equal to the test pressure divided by 1.1 and held for a sufficient time to permit inspection of the vessel. Any leaks that are present, except for leakage that might occur at temporary test closures for those openings intended for welded connections, shall be corrected, and the vessel shall be retested. The visual inspection of the vessel at the required test pressure divided by 1.1 may be waived, provided: *(1)* a suitable gas leak test is applied; *(2)* substitution of the gas leak test is by agreement reached between Manufacturer and Inspector; *(3)* all welded seams that will be hidden by assembly are given a visual examination for workmanship prior to assembly;

Pneumatic Pressure Test Requirements for Pressure Vessels – Section VIII, Division 1	
2007 Edition	**2021 Edition**
	(4) the vessel will not contain a “lethal” substance.
Paragraph UG-100*(e)* states: *(e)* Vessels, except for those in lethal service, may be painted or otherwise coated either internally or externally, and may be lined internally, prior to the pressure test. However, the user is cautioned that such painting / coating /lining may mask leaks that would otherwise have been detected during the pressure test.	**Paragraph UG-100*(f)*** states: *(f) Painting and Coating* *(1)* Unless permitted by the user or his designated agent, pressure-retaining welds of vessels shall not be painted or otherwise coated either internally or externally prior to the pneumatic pressure test. *(2)* When painting or coating prior to the pneumatic test is permitted, or when internal nonmetallic linings are to be applied, the pressure-retaining welds shall first be leak tested in accordance with Section V, Article 10. Such a test may be waived with the approval of the user or his designated agent. *(3)* Vessels for lethal service [see UW-2*(a)*] *(-a)* shall not be painted or coated either internally or externally prior to the pneumatic pressure test *(-b)* shall not be internally lined by mechanical or welded attachments prior to the pneumatic pressure test unless the requirements of UCL-51 are followed
The 2007 edition of Section VIII, Division 1 does not include Paragraph UG-100*(g)*.	**Paragraph UG-100*(g)*** states: *(g)* Custom-designed flange assemblies, including modified standard flange assemblies where additional calculations are required, within the geometric scope of this Division (see Mandatory Appendix 2 and UG-34) shall be tested with gaskets and bolting that meet the following requirements: *(1)* be assembled with *(-a)* the identical gasket used for operation of the pressure vessel, or *(-b)* a gasket with the same outside diameter, inside diameter, thickness, gasket factor (m), and minimum seating stress (y) used in the flange design calculations *(2)* be assembled with bolting having identical allowable stress at room temperature as used in the design calculations The user or his/her designated agent may allow either or both requirements to be waived by including such a statement in the General Notes section of Form U-DR-1 or Form U-DR-2, or equivalent. The use of test gaskets and bolting with properties differing from those used in the design calculation does not necessarily verify the integrity of flanged joints.

Based on the side-by-side comparation shown in Table 7.3, pneumatic pressure testing rules specified in Paragraph UG-100 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC are not the same. The differences are discussed below.

Paragraph UG-100*(b)*

According to rules specified in Paragraph UG-100*(b)*, the pneumatic test pressure, P_T, must be established based on the following conditions.

- Minimum pneumatic test pressure, P_T, for the materials of which the pressure vessel is constructed is based on rules specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. These rules state that the minimum pneumatic test pressure shall be calculated using the following equation.

$$P_T = 1.1\ \text{MAWP}\left(\frac{S_T}{S}\right)$$

- Maximum P_T is not specified in either the 2007 or 2021 edition of Section VIII, Division 1 of the ASME BPVC. However, rules specified in the 2007 and 2021 editions state that in no case shall the pneumatic test pressure exceed 1.1 times the basis for the calculated test pressure as defined in Mandatory Appendix 3-2. The calculated test pressure, P_T, is defined in Mandatory Appendix 3 – Definitions, Paragraph 3-2 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. This definition states that the requirements for determining the test pressure based on calculations are outlined in UG-99*(c)* for the hydrostatic test and in UG-100*(b)* for the pneumatic test. The basis for calculated test pressure in either of these paragraphs is the highest permissible internal pressure as determined by the design formulas, for each element of the vessel using nominal thicknesses with corrosion allowances included and using the allowable stress values given in Section II, Part D, Tables 1A and 1B, as applicable, of the ASME BPVC for the temperature of the test (See Sect. 4.4.1 of the report).

Paragraph UG-100*(d)*

Rules specified in Paragraphs UG-100*(d)* in the 2021 editions are subdivided and expanded to include separate rules for independent pressure chambers and dependent pressure chambers.

Paragraph UG-100*(e)*

Rules specified in Paragraphs UG-100*(e)* in the 2021 edition provide conditions for waving the required visual examination at the test pressure. These rules were not included in the 2007 edition.

Paragraph UG-100*(f)*

Rules specified in Paragraphs UG-100*(e)* in the 2007 edition correspond to revised rules for painting and coating specified in the UG-100*(f)* in the 2021 edition. Rules specified in Paragraph UG-100*(f)* were not included in the 2007 edition.

Paragraph UG-100*(f)(2)* in the 2021 edition states that when painting or coating prior to the pneumatic test is permitted, or when internal nonmetallic linings are to be applied, the pressure-retaining welds shall first be leak tested in accordance with Section V, Article 10. Such a test may be waived with the approval of the user or his designated agent. Leak testing requirements prescribed in Section V, Article 10 are discussed in Sect. 6.4 of this report.

Paragraph UG-100*(g)*

Rules specified in Paragraphs UG 100*(g)* in the 2021 edition for custom-designed flange assemblies were not included in the 2007 edition.

Figure 7.3 of this report compares the maximum allowable design stress and pneumatic pressure testing limits specified in Paragraph UG-100 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC to plastic collapse stress limit discussed in Sect. 4.8.1 of this report. Note that the minimum

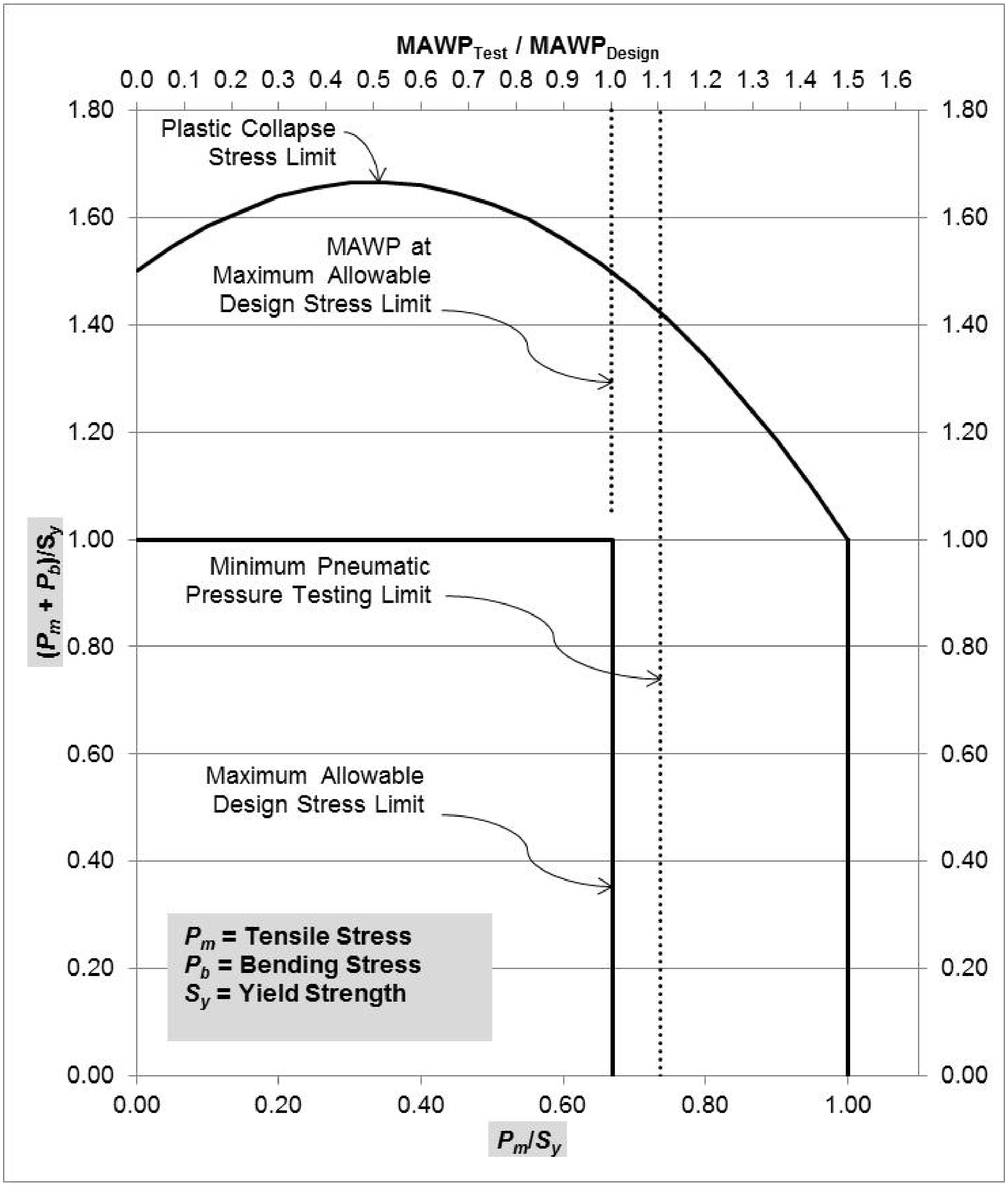

Fig. 7.3 Comparison of maximum allowable design stress and pneumatic pressure testing limits specified in the 2007 and 2021 edition of Section VIII, Division 1 of the ASME BPVC to plastic collapse stress limit

pneumatic pressure testing limit in these figures corresponds to a MAWP that is based on a maximum allowable design stress limit equal to $2/3\ S_y$.

It is important to note that:

- Rules in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC do not specify a minimum or maximum pneumatic test pressure duration. The rules state that the pressure must be held for sufficient time to permit inspection of the pressure vessel.
- Although the additional rules specified in Paragraph UG-100 expand the scope of hydrostatic testing requirements provided in the 2021 edition of Section VIII, Division 1 of the ASME BPVC, they do not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC.

7.1.3 Basis for Pressure Testing Limits in Section VIII, Division 2 of the ASME BPVC

The objective of design rules specified in Section VIII, Division 2 of the ASME BPVC is to use design-by-rule or design-by-analysis to ensure that the pressure vessel design stress intensity values in Table 2A and 2B or Table 5A and 5B, as applicable, are not exceeded under all loading conditions specified in the User's Design Specification. Equations for establishing design stress intensity values are specified in Part 4 – Design by Rule Requirements, Paragraph 4.1.6.1 – Design Condition in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC as follows.

$$P_m \leq S \tag{4.1.1}$$

$$P_m + P_b \leq 1.5\,S \tag{4.1.2}$$

where:

P_m is the primary membrane stress
P_b is the primary bending stress
S is the allowable stress

These rules ensure that when the allowable stress, S, equals two-thirds or less of the specified minimum yield strength, S_y, of the materials the maximum allowable primary membrane stress, P_m, does not exceed $2/3\ S_y$. It also ensures that the maximum allowable primary membrane stress plus primary bending stress, $P_m + P_b$ does not exceed S_y. These maximum allowable stress limits are consistent with the principles of limit design theory discussed in Sect. 4.6 and the plastic collapse requirements discussed in Sect. 4.8.2 of this report.

7.1.3.1 ASME BPVC, Section VIII, Division 2 – Hydrostatic Pressure Testing Requirements for Pressure Vessels

Hydrostatic pressure testing requirements for pressure vessels that have been designed and fabricated in accordance with rules specified in Section VIII, Division 2 are provided in Paragraph 8.2.1 – Test Pressure and Paragraph 4.1.6.2 – Test Condition in the 2007 and 2021 editions of the ASME BPVC. Paragraph 8.2.1 provides equations for establishing the minimum hydrostatic test pressure and Paragraph 4.1.6.2 provides equations for establishing the maximum hydrostatic test pressure. The equations specified in Paragraph 8.2.1 and Paragraph 4.1.6.2 for establishing the minimum and maximum hydrostatic test pressure, P_T, are compared below.

<u>Comparison of Minimum Hydrostatic Test Pressure Specified in Section VIII, Division 2</u>

Rules specified in Paragraph 8.2.1*(a)* – Test Pressure in the 2007 edition state that the minimum hydrostatic test pressure, P_T, shall be the greater of:

$$P_T = 1.43\ \text{MAWP} \tag{8.1}$$

or

$$P_T = 1.25 \text{ MAWP} \left(\frac{S_T}{S}\right) \tag{8.2}$$

where:

MAWP is the maximum allowable working pressure

P_T is the minimum test pressure

S is the allowable stress evaluated at the design temperature

S_T is the allowable stress evaluated at the test temperature

Rules specified in specified in Paragraph 8.2.1*(a)* – Test Pressure in the 2021 edition state that the minimum hydrostatic test pressure, P_T, shall be computed using the following equation.

$$P_T = \frac{\gamma_{St}}{S} \text{MAWP} \left(\frac{S_T}{S}\right) \tag{8.1}$$

where:

MAWP is the maximum allowable working pressure

$\frac{\gamma_{St}}{S}$ is the test condition load factor considering the ratio of the allowable stress at the test condition to the allowable stress at the design condition. The test condition load factor for hydrostatic testing equals 1.25 for Class 1 or Class 2 construction.

P_T is the minimum test pressure

S is the allowable stress evaluated at the design temperature

S_T is the allowable stress evaluated at the test temperature

Note that after substituting the test condition load factor, $\frac{\gamma_{St}}{S} = 1.25$, into equation (8.1) in the 2021 edition, equation (8.2) in the 2007 edition and equation (8.1) in the 2021 edition are equivalent.

Comparison of Maximum Hydrostatic Test Pressure Specified in Section VIII, Division 2

Rules specified in Paragraph 4.1.6.2*(a)(1)* in the 2007 edition of Section VIII, Division 2 of the ASME BPVC state that when a hydrostatic pressure test is performed, the calculated P_m shall not exceed the applicable limit given below:

$$P_m \leq 0.95\ S_y \tag{4.1.3}$$

Rules specified in Paragraph 4.1.6.2*(a)* in the 2021 edition of Section VIII, Division 2 of the ASME BPVC state that when a hydrostatic pressure test is performed, the calculated P_m shall not exceed the applicable limit given below, where β_T equals 0.95 for Class 1 and Class 2 construction.

$$P_m \leq \beta_T S_y \tag{4.1.3}$$

where:

P_m is the primary membrane stress

P_b is the primary bending stress

S_y is the specified yield strength

Rules specified in Paragraph 4.1.6.2*(a)(2)* in the 2007 edition of Section VIII, Division 2 of the ASME BPVC state that when a hydrostatic pressure test is performed, the calculated $P_m + P_b$ shall not exceed the applicable limit given below:

$$P_m + P_b \leq 1.43\ S_y \qquad \text{for } P_m = 0.67 S_y \tag{4.1.4}$$

$$P_m + P_b \leq \left(2.43S_y - 1.5P_m\right) \qquad \text{for } 0.67S_y < P_m \leq 0.95\, S_y \qquad (4.1.5)$$

Rules specified in Paragraph 4.1.6.2*(b)(1)* and *(2)* in the 2021 edition of Section VIII, Division 2 of the ASME BPVC state that a calculated P_m shall not exceed the applicable limit given below where the pressure test factor, β_T equals 0.95 and γ_{min} equals $1.5\beta_T$ for hydrostatic test for Class 1 and Class 2 construction.

$$P_m + P_b \leq \gamma_{min}S_y \qquad \text{for } P_m \leq \frac{1}{1.5}S_y \qquad (4.1.4)$$

$$P_m + P_b \leq \left[\frac{1-\gamma_{min}}{\beta_T - \frac{1}{1.5}}\right]P_m - \left[\left[\frac{1-\gamma_{min}}{\beta_T - \frac{1}{1.5}}\right]\beta_T - 1\right]S_y \qquad \text{for } \frac{1}{1.5}S_y < P_m \leq \beta_T S_y \qquad (4.1.5)$$

where:

P_m is the primary membrane stress

P_b is the primary bending stress

S_y is the specified yield strength

Note that after substituting the pressure test factor, $\beta_T = 0.95$, into equations (4.1.4) and (4.1.5) in the 2021 edition, equations (4.1.4) and (4.1.5) in the 2007 edition and equations (4.1.4) and (4.1.5) in the 2021 edition are equivalent.

Figures 7.4 of this report compares the maximum allowable design stress and hydrostatic pressure testing limits specified in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC to plastic collapse stress limit discussed in Sect. 4.8.2 of this report.

The test pressure limits incorporated into the 2007 edition are similar to the rules used in the European Pressure Equipment Directive (PED). The Section VIII Committee decided to adopt similar test pressure requirements with European practice to be consistent with the allowable stress basis. However, a test pressure in accordance with Equation 8.1 (shown above) may exceed the 95% stress limit during hydrotest when the MAWP is based on the maximum allowable stress value (1.43*2/3=0.953). When the MAWP of the vessel produces stresses in excess of 99.7% (0.95/0.953) of the allowable stress based on 2/3 yield, the maximum stresses associated with the limits as established in 4.1.6.2 may be exceeded. Since the hydrotest is not the only consideration for compliance with the European PED, imposing this requirement on all vessels even if there is no intention of compliance with the PED was determined to be onerous. In 2019, the minimum hydrotest test requirements was reset to 1.25 (same as prior to the 2007 Edition, see Article T-3 2006 Edition). The upper limit remains at 95% of the allowable stress. Any intermediate value of pressure may be used if a user would still require the vessel to be tested to 1.43*MAWP.

It is important to note that:

- The minimum hydrotest pressure specified in the 2004 edition of Section VIII, Division 2 of the ASME BPVC is 1.25 MAWP, and the calculated primary membrane stress intensity, P_m, is limited to 90% of the tabulated yield strength, S_y, at test temperature. However, the ASME Section VIII Committee decided to adopt test pressure requirements provided in the European Pressure Equipment Directive (PED) [20] for the 2007 edition of Section VIII, Division 2 of the ASME BPVC. Requirements in the PED states that the hydrostatic test pressure shall be no less than either of the following:

a. that corresponding to the maximum loading to which the pressure equipment may be subject in service taking into account its maximum allowable pressure and its maximum allowable temperature, multiplied by the coefficient 1.25,
b. the maximum allowable pressure multiplied by the coefficient 1.43, whichever is the greater.

These requirements permit the primary membrane stress intensity, P_m, to equal 95.3% of the tabulated yield strength, S_y, at test temperature (i.e., $1.43 \times 2/3\,S_y = 0.953\,S_y$). However, rules in Paragraph 4.1.6.2*(a)(1)* in the 2007 edition of Section VIII, Division 2 of the ASME BPVC limit the primary membrane stress intensity, P_m, to equal 95% of the tabulated yield strength, S_y, at test temperature.

In the 2021 edition of Section VIII, Division 2 of the ASME BPVC, the minimum hydrotest test requirement equals 1.25 MAWP which corresponds to the value prior to the 2007 edition and the upper limit of the primary membrane stress intensity, P_m, is $0.95\,S_y$. Any intermediate test pressure value may be used if a user requires the pressure vessel to be tested to 1.43 MAWP.

- The maximum and minimum hydrostatic test pressures for a pressure vessel that is designed and fabricated in accordance with rules specified in the 2007 edition of Section VIII, Division 2 of the ASME BPVC are equal when MAWP is based on an allowable primary membrane stress, P_m, equal to $2/3\,S_y$ (i.e., 0.95×1.5 MAWP $= 1.43$ MAWP). Controlling the hydrostatic test pressure to a pressure of at least 1.43 MAWP but not more than 1.43 MAWP could be problematic. Consequently, the primary membrane design stress may need to be reduced to a value less than $2/3\,S_y$ to satisfy the minimum test pressure requirement, maintain a primary membrane stress below the primary membrane stress limit of $0.95\,S_y$, and provide a margin for hydrostatic test pressure control.
- Pressure tests of pressure vessels constructed in accordance with ASME BPVC rules are performed after fabrication is completed primarily to verify the leak tight integrity of the pressure boundary. These pressure tests are also performed to identify gross deformations or anomalies that may indicate design errors, material deficiencies, or weld defects. A successful pressure testing of a boiler or pressure vessel is required before the Authorized Inspector will approve application of the Certification Mark by the Manufacturer. Therefore, hydrostatic testing requirements provided in the 2021 edition of Section VIII, Division 2 of the ASME BPVC do not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC.

7.1.3.2 ASME BPVC, Section VIII, Division 2 – Pneumatic Pressure Testing Requirements for Pressure Vessels

Pneumatic pressure testing requirements for pressure vessels that have been designed and fabricated in accordance with rules specified in Section VIII, Division 2 are provided in Paragraph 8.2.1 – Test Pressure in the 2007 and 2021 editions and Paragraph 4.1.6.2 – Test Condition in the 2007 and 2021 editions of the ASME BPVC.

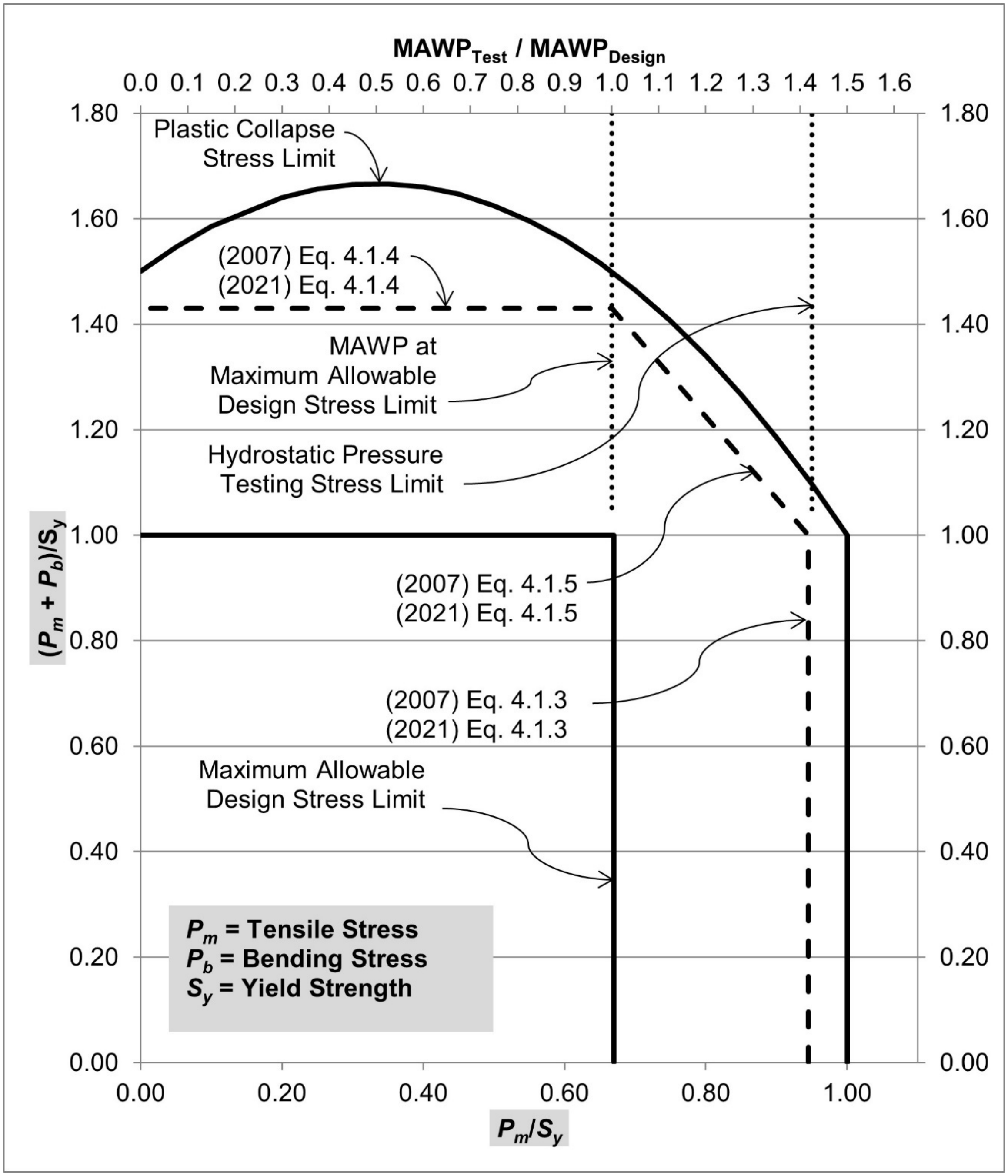

Fig. 7.4 Comparison of maximum allowable design stress and hydrostatic pressure testing limits specified in the 2021 edition of Section VIII, Division 2 of the ASME BPVC to plastic collapse stress limit

Pneumatic pressure testing requirements for pressure vessels are specified in Paragraph 8.3.1 – Test Pressure in the 2007 edition and Paragraph 8.2.1 – Test Pressure in the 2021 editions of Section VIII, Division 2 of the ASME BPVC. Equations specified in these paragraphs for establishing the minimum and maximum pneumatic test pressure, P_T, are compared below.

Comparison of Minimum Pneumatic Test Pressure Specified in Section VIII, Division 2

Rules specified in Paragraph 8.3.1*(a)* – Test Pressure in the 2007 edition state that the minimum pneumatic test pressure, P_T, shall be computed by the following equation.

$$P_T = 1.15 \text{ MAWP} \left(\frac{S_T}{S}\right) \tag{8.3}$$

where:

MAWP is the maximum allowable working pressure

P_T is the minimum test pressure

S is the allowable stress evaluated at the design temperature

S_T is the allowable stress evaluated at the test temperature

Rules specified in Paragraph 8.2.1*(a)* – Test Pressure in the 2021 edition state that the minimum test pressure, P_T, shall be computed using the following equation:

$$P_T = \frac{\gamma_{St}}{S} \text{MAWP} \left(\frac{S_T}{S}\right) \tag{8.1}$$

where:

MAWP is the maximum allowable working pressure

$\frac{\gamma_{St}}{S}$ is the test condition load factor considering the ratio of the allowable stress at the test condition to the allowable stress at the design condition. The test condition load factor for pneumatic testing equals 1.15 for Class 1 or Class 2 construction.

P_T is the minimum test pressure

S is the allowable stress evaluated at the design temperature

S_T is the allowable stress evaluated at the test temperature

Note that after substituting the test condition load factor, $\frac{\gamma_{St}}{S} = 1.15$, into equation (8.1) in the 2021 edition, equation (8.3) in the 2007 edition and equation (8.1) in the 2021 edition are equivalent.

Comparison of Maximum Pneumatic Test Pressure Specified in Section VIII, Division 2

Rules specified in Paragraph 4.1.6.2*(b)(1)* in the 2007 edition of Section VIII, Division 2 of the ASME BPVC state that a calculated P_m shall not exceed the applicable limit given below:

$$P_m \leq 0.80\, S_y \tag{4.1.6}$$

Rules specified in Paragraph 4.1.6.2*(a)* in the 2021 edition of Section VIII, Division 2 of the ASME BPVC state that the calculated P_m shall not exceed the applicable limit given below, where β_T equals 0.80 for Class 1 and Class 2 construction.

$$P_m \leq \beta_T S_y \tag{4.1.3}$$

where:

P_m is the primary membrane stress

P_b is the primary bending stress

S_y is the specified yield strength

Rules specified in Paragraph 4.1.6.2*(b)(2)* in the 2007 edition of Section VIII, Division 2 of the ASME BPVC state that a calculated $P_m + P_b$ shall not exceed the applicable limit given below:

$$P_m + P_b \le 1.20\, S_y \qquad \text{for } P_m = 0.67 S_y \qquad (4.1.7)$$

$$P_m + P_b \le \left(2.20 S_y - 1.5 P_m\right) \qquad \text{for } 0.67 S_y < P_m \le 0.80\, S_y \qquad (4.1.8)$$

Rules specified in Paragraph 4.1.6.2*(b)(1)* and *(2)* in the 2021 edition of Section VIII, Division 2 of the ASME BPVC state that a calculated P_m shall not exceed the applicable limit given below where β_T equals 0.80 and γ_{min} equals $1.5\beta_T$ for pneumatic test for Class 1 and Class 2 construction.

$$P_m + P_b \le \gamma_{min} S_y \qquad \text{for } P_m \le \frac{1}{1.5} S_y \qquad (4.1.4)$$

$$P_m + P_b \le \left[\frac{1-\gamma_{min}}{\beta_T - \frac{1}{1.5}}\right] P_m - \left[\left[\frac{1-\gamma_{min}}{\beta_T - \frac{1}{1.5}}\right]\beta_T - 1\right] S_y \qquad \text{for } \frac{1}{1.5} S_y < P_m \le \beta_T S_y \qquad (4.1.5)$$

where:

P_m is the primary membrane stress
P_b is the primary bending stress
S_y is the specified yield strength

Note that after substituting the pressure test factor, $\beta_T = 0.80$, into equations (4.1.4) and (4.1.5) in the 2021 edition, equations (4.1.7) and (4.1.8) in the 2007 edition and equations (4.1.7) and (4.1.8) in the 2021 edition are equivalent.

Figures 7.5 of this report compares the maximum allowable design stress and pneumatic pressure testing limits specified in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC to plastic collapse stress limit discussed in Sect. 4.8.2 of this report.

It is important to note that:

- The maximum and minimum pneumatic test pressures for a pressure vessel that is designed and fabricated in accordance with rules specified in the 2007 edition of Section VIII, Division 2 of the ASME BPVC are equal when MAWP is based on an allowable primary membrane stress, P_m, equal to $2/3\, S_y$ (i.e., $0.80 \times 1.5\text{MAWP} = 1.20$ MAWP).
- The pneumatic testing requirements provided in the 2021 edition of Section VIII, Division 2 of the ASME BPVC do not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC.

Requirements for Leak Testing in Section VIII, Division 2

Requirements for leak testing are provided in Paragraph 7.7 in the 2007 and 2021 editions in Section VIII, Division 2. These requirements state that leak testing shall be performed in accordance with Section V, Article 10 in addition to hydrostatic test or pneumatic test. Methods and requirements for performing leak tests are in accordance with Section V, Article 10 are discussed in Sect 6.4 of this report.

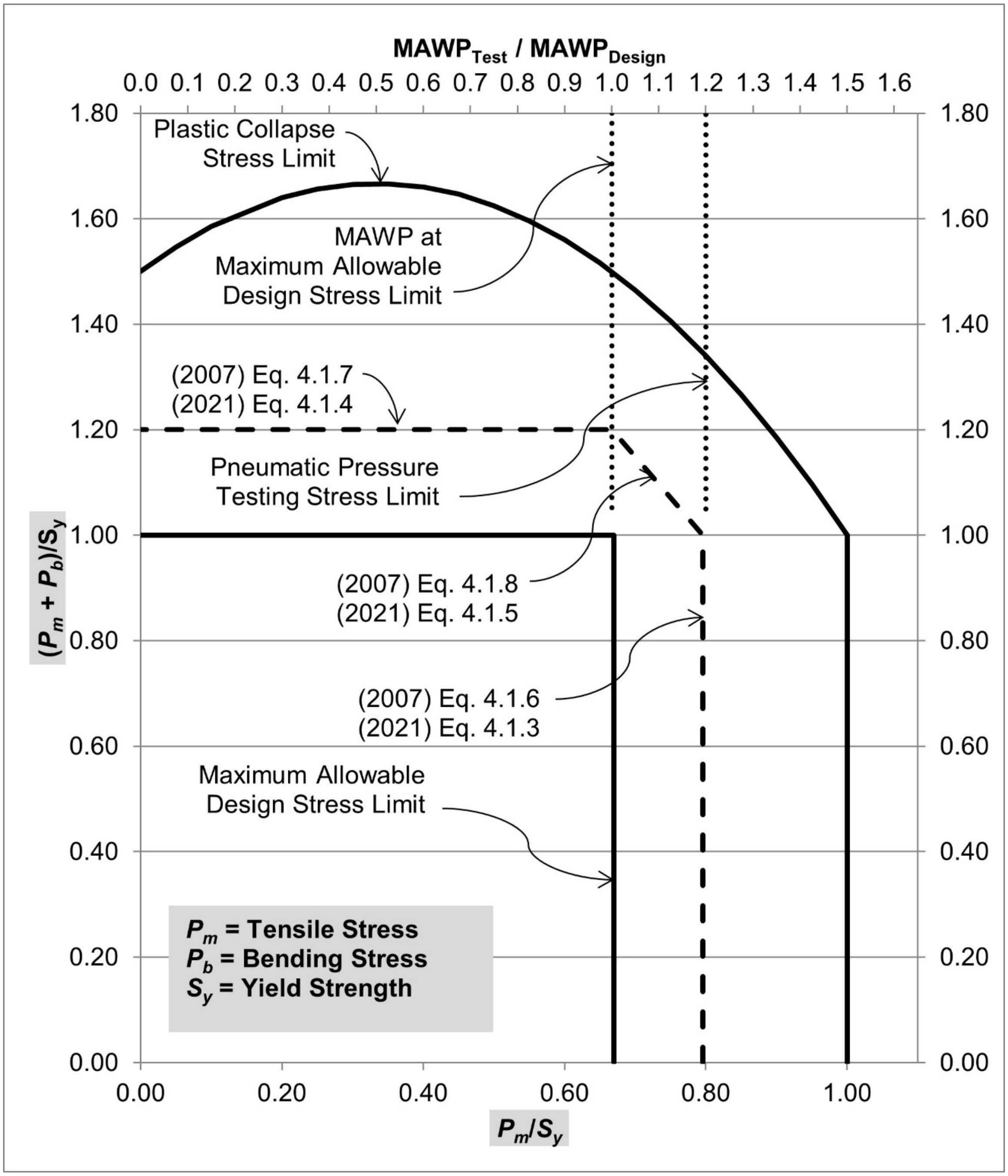

Fig. 7.5 Comparison of maximum allowable design stress and pneumatic pressure testing limits specified in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC to plastic collapse stress limit

7.1.4 Comparison of Pressure Testing Requirement in the ASME BPVC

A comparison of pressure testing requirement specified in the 2007 and 2021 editions of the ASME BPVC is presented in Table 7.4 of this report. These pressure testing requirements are discussed further in Sects. 7.1.1, 7.1.2, and 7.1.3 of this report.

Table 7.4 Comparison of pressure test limits specified in the 2007 and 2021 editions of the ASME BPVC

ASME BPVC and Test Type	Pressure Test and Membrane Stress Limits
Section I Hydrostatic Test (See Sect. 7.1.1.1 and Fig. 7.1 of this report)	2007 – minimum hydrostatic test pressure – 1.5 MAWP 2007 – maximum general membrane stress, P_m, limit – 0.9 S_y* 2021 – minimum hydrostatic test pressure – 1.5 MAWP 2021 – maximum general membrane stress, P_m, limit – 0.9 S_y*
Section VIII, Division 1 Hydrostatic Test (See Sect. 7.1.2.1 and Fig. 7.2 of this report)	2007 – minimum hydrostatic test pressure – 1.3 MAWP 2007 – If the pressure vessel is subjected to visible permanent distortion, the Inspector shall reserve the right to reject the vessel. 2021 – minimum hydrostatic test pressure – 1.3 MAWP 2021 – If the pressure vessel is subjected to visible permanent distortion, the Inspector shall reserve the right to reject the vessel.
Section VIII, Division 1 Pneumatic Test (See Sect. 7.1.2.2 and Fig. 7.3 of this report)	2007 – minimum pneumatic test pressure – 1.1 MAWP 2007 – maximum general membrane stress limit not specified 2021 – minimum pneumatic test pressure – 1.1 MAWP 2021 – maximum general membrane stress limit not specified
Section VIII, Division 2 Hydrostatic Test (See Sect. 7.1.3.1 and Fig. 7.4 of this report)	2007 – minimum hydrostatic test pressure – greater of 1.43 MAWP or 1.25 MAWP(S_T/S) 2007 – maximum general membrane stress, P_m, limit – 0.95 S_y 2021 – minimum hydrostatic test pressure – 1.25 MAWP(S_T/S)† 2021 – maximum general membrane stress, P_m, limit – 0.95 S_y†
Section VIII, Division 2 Pneumatic Test (See Sect. 7.1.3.2 and Fig. 7.5 of this report)	2007 – minimum pneumatic test pressure – 1.15 MAWP(S_T/S) 2007 – maximum general membrane stress, P_m, limit – 0.8 S_y 2021 – minimum pneumatic test pressure – 1.15 MAWP(S_T/S)† 2021 – maximum general membrane stress, P_m, limit – 0.8 S_y†

*No part of the boiler shall be subjected to a general membrane stress greater than 90% of its yield strength (0.2% offset) at test temperature.
†Class 1 and Class 2 Construction

7.2 ALTERNATIVE PRESSURE TESTING

Alternative pressure testing rules are provided in Part 8 – Pressure Testing Requirements in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. According to alternative pressure testing requirements specified in Paragraph 8.4 in the 2007 edition and Paragraph 8.3 in the 2021 edition, in cases where it is desirable to pressure test a pressure vessel partially filled with liquid, the requirements of Paragraph 8.3 in the 2007 edition or Paragraph 8.2 in the 2021 edition must be met, except the pneumatic pressure applied above the liquid level must at no point result in a total pressure that causes the general membrane stress to exceed 80% of the specified minimum yield strength of the material at test temperature.

Requirements for leak tightness testing are specified in Paragraph 8.4.2 in the 2007 edition and Paragraph 8.3.2 in the 2021 edition as follows.

a) Leak tightness tests include a variety of methods of sufficient sensitivity to allow for the detection of leaks in pressure elements, including, but not limited to the use of direct pressure and vacuum bubble test methods, and various gas detection tests.

b) The selection of a leak tightness test to be employed should be based on the suitability of the test for the particular pressure element being tested.
c) The metal temperature for leak tightness tests must be in accordance with Paragraph 8.3.4.a. Additionally, the temperature must be maintained within the specified range for the test equipment being used.
d) Leak tightness tests must be performed in accordance with Article 10 of Section V.

Methods and requirements for performing leak tests are in accordance with Section V, Article 10 are discussed in Sect 6.4 of this report.

7.3 PROOF TESTING

Proof testing of boilers and pressure vessels is another type of pressure test that can be performed for the purpose of establishing the MAWP of those elements or component parts for which the thickness cannot be determined by means of the design rules. Rules for proof testing are provide in the 2007 and 2021 editions of Section I and Section VIII, Division 1 but not in Section VIII, Division 2 of the ASME BPVC.

7.3.1 Proof Testing Requirements in Section I of the ASME BPVC

Paragraph PG-18 in the 2007 and 2021 editions of Section I of the ASME BPVC states that where no rules are given for calculating the strength of a boiler or any part thereof, the Manufacturer may establish MAWP by testing a full-size sample in accordance with one of the three test methods specified in Nonmandatory Appendix A – Explanation of The Code Containing Matter Not Mandatory Unless Specifically Referred to in the Rules of the Code, Paragraph A-22 – Proof Tests to Establish Maximum Allowable Working Pressure in the 2007 and 2021 editions of Section I of the ASME BPVC. Procedures for determining the internal MAWP based on the following proof test methods are described in Paragraph A-22.6.

- Strain Measurement Test
- Displacement Measurement Test
- Burst Test

According to rules specified in Paragraph A-22.3.2 in the 2007 and 2021 editions of Section I of the ASME BPVC, in the Strain Measurement Test and the Displacement Measurement Test, the hydrostatic pressure in the pressure part must be increased gradually until approximately one-half the anticipated maximum allowable working pressure is reached. Thereafter, the test pressure must be increased in steps of approximately one tenth or less of the anticipated maximum allowable working pressure until the pressure required by the test procedure is reached. The pressure must be held stationary at the end of each increment for a sufficient time to allow the observations required by the test procedure to be made and must be released to zero to permit determination of any permanent strain or displacement after any pressure increment that indicates an increase in strain or displacement over the previous equal pressure increment. Equations are provided for using proof test data to compute MAWP.

According to rules specified in Paragraph A-22.6.3 in the 2007 and 2021 editions of Section I of the ASME BPVC, the Burst Test may be used for pressure parts under internal pressure when constructed of any material permitted to be used under the rules of Section I. The maximum allowable working pressure of any component part proof tested by this method must be established by a hydrostatic test to failure by rupture of a full-size sample of such pressure part. The hydrostatic pressure at which rupture occurs must be determined. Alternatively, the test may be stopped at any pressure before rupture that will satisfy the requirements for the desired maximum allowable working pressure. The item so tested must not be used for Code construction. Equations for cast materials and other than cast materials are provided for using burst test data to compute MAWP.

7.3.2 Proof Testing Requirements in Section VII, Division 1 of the ASME BPVC

Requirements for proof testing to establish MAWP are provided in Paragraph UG-101 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. Provision is made in these rules for two types of tests to determine the internal maximum allowable working pressure:

1. tests based on yielding of the part to be tested. These tests are limited to materials with a ratio of minimum specified yield to minimum specified ultimate strength of 0.625 or less.
2. tests based on bursting of the part.

Requirements for permitted proof test procedures are specified in the following paragraphs in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC.

- Paragraph UG-101*(l)* – Brittle-Coating Test Procedure
- Paragraph UG-101*(m)* – Bursting Test Procedure
- Paragraph UG-101*(n)* – Strain Measurement Test Procedure
- Paragraph UG-101*(o)* – Displacement Measurement Test Procedure
- Paragraph UG-101*(p)* – Procedure for Vessels Having Chambers of Special Shape Subject to Collapse

Selection of a particular proof test procedure depends on its applicability to the type of loading and to the material used in construction. A brief description of each proof test procedure follows. It is important to note that the corresponding proof test equations in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC are the same.

7.3.2.1 Brittle-Coating Test Procedure

According to Paragraph UG-101*(l)(1)*, the brittle-coating test procedure may be used only for pressure vessels and pressure vessel parts under internal pressure, constructed of materials having a definitely determinable yield point. Component parts that require proof testing must be coated with a brittle coating. The parts being proof tested must be examined between pressure increments for signs of yielding as evidenced by flaking of the brittle coating, or by the appearance of strain lines. The application of pressure must be stopped at the first sign of yielding, or if desired, at some lower pressure. The MAWP at test temperature for parts tested under this Paragraph must be computed by one of the following formulas specified in UG-101*(l)(2)*.

7.3.2.2 Bursting Test Procedure

According to Paragraph UG-101*(m)(1)*, the bursting test procedure may be used for pressure vessels or pressure vessel parts under internal pressure when constructed of any material permitted to be used under the rules of Section VIII, Division 1 of the ASME BPVC. The MAWP of any component part proof tested by this method must be established by a hydrostatic test to failure by rupture of a full-size sample of such pressure part. The hydrostatic pressure at which rupture occurs must be determined. Alternatively, the test may be stopped at any pressure before rupture that will satisfy the requirements for the desired MAWP. The MAWP at test temperature for parts tested under this Paragraph must be computed by one of the following formulas specified in UG-101*(m)(2)*.

7.3.2.3 Strain Measurement Test Procedure

According to Paragraph UG-101*(n)(1)*, the strain measurement test procedure may be used for pressure vessels or pressure vessel parts under internal pressure, constructed of any material permitted to be used under the rules of Section VIII, Division 1 of the ASME BPVC. Strains must be measured in the direction of the maximum stress at the most highly stressed parts by means of strain gages of any type capable of indicating incremental strains to 0.00005 in. / in. (0.005%). It is recommended that the gage length be such that the expected maximum strain within the gage length does not exceed the expected average strain within the gage length by more than 10%. The strain gages and the method of attachment must be shown by test to be reliable, and the results documented for a range of strain values that is at least 50% higher than expected, when used with the material surface finish and configuration being considered. The MAWP at test temperature for parts tested under this Paragraph must be computed by one of the following formulas specified in Paragraph UG-101*(n)(4)*.

7.3.2.4 Displacement Measurement Test Procedure

According to Paragraph UG-101*(o)(1)*, the displacement measurement test procedure may be used only for pressure vessels and pressure vessel parts under internal pressure, constructed of materials having a definitely determinable yield point. Displacement must be measured at the most highly stressed parts by means of measuring devices of any type capable of measuring to 0.001 in. (0.02 mm). The displacement may be measured between two diametrically opposed reference points in a symmetrical structure, or between a reference point and a fixed base point. The MAWP at test temperature for parts tested under this Paragraph must be computed by one of the following formulas specified in UG-101*(o)(5)*.

7.3.2.5 Procedure for Vessels Having Chambers of Special Shape Subject to Collapse

According to Paragraph UG-101*(p)(1)*, pressure chambers of vessels, portions of which have a shape other than that of a complete circular cylinder or formed head, and also jackets of cylindrical vessels which extend over only a portion of the circumference, which are not fully staybolted as required by UG-28*(i)*, must withstand without excessive deformation a hydrostatic test of not less than three times the desired maximum allowable working pressure.

7.3.3 Proof Testing Requirements in Section VIII, Division 2 of the ASME BPVC

Rules for proof testing are not provided in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC.

8. OVERPRESSURE PROTECTION

Rules specified in the ASME BPVC for design and fabrication of boilers and pressure vessels ensure an acceptable level of safety against unplanned releases of hazardous materials and stored energy by:

1. providing a minimum design margin against plastic collapse of at least 1.5 as discussed in Sect. 4.1.2 of this report, and
2. requiring overpressure protection for conditions when the pressure exceeds MAWP.

These separate, but complementary, criteria provide duplication of critical safety functions necessary for increased reliability and satisfactory in-service performance.

Overpressure protection is normally provided by pressure relief devices (e.g., safety valves, pressure relief valves, rupture disks, nonreclosing pressure relief devices, etc.) capable of venting excess pressure through a designated release path but can also be provided by a method referred to in the ASME BPVC as "system design." Discussions about overpressure protection by system design are presented in Sects. 8.1 through 8.3 of this report. Further guidance on overpressure protection by systems design is provided in a document by Karcher [15] and in WRC Bulletin 498 [16].

Paragraph 4.7.3.1 in the 2001 edition of NFPA 59A states that the capacity of pressure relief devices for stationary LNG containers must be based on exposure to fire. Equations for computing the required pressure relieving capacity for fire exposure are provided in Paragraph 4.7.3.4 in the 2001 edition of NFPA 59A. In addition, overpressure protection for pressure vessels constructed to rules specified in the 2021 edition of Section VIII, Division 2 should include consideration of loads due to deflagration as discussed in Sect. 4.2.3 of this report.

Section XIII – Rules for Overpressure Protection in the 2021 edition of the ASME BPVC provides rules for the overpressure protection of pressurized equipment such as boilers, pressure vessels, and piping systems. This standard provides requirements for topics such as design, material, inspection, assembly, testing, and marking for pressure relief valves, rupture disk devices, pin devices, spring-actuated non-reclosing devices, and temperature and pressure relief valves. This standard also covers devices in combination, capacity and flow resistance certification, authorization to use the ASME Certification Mark, installation, and overpressure protection by system design. As a Reference Code, rules specified in Section XIII are only mandatory when referenced from a Construction Code.

8.1 SECTION I – OVERPRESSURE PROTECTION REQUIREMENTS FOR BOILERS

The 2021 edition of Section I adopts portions of the new ASME BPVC Section XIII, Rules for Overpressure Protection. Section I requirements formerly in PG- 69.1.2; PG-69.1.3; PG-69.1.5; PG-69.2.1 through PG-69.2.6; PG-69.6; and Nonmandatory Appendix A, A-311, have been transferred to Section XIII, Part 9, Capacity and Flow-Resistance Certification. Table G-1-1 – Cross-Reference List in Nonmandatory Appendix G – Guide to the Relocation of Requirements for Capacity Certification of Pressure Relief Valves in Section I lists the new locations for these requirements.

Rules for certifying the capacity of pressure relief valve are specified in Paragraph PG-69 in the 2021 edition of Section I of the ASME BPVC. Paragraph PG-69.2 states that the relieving capacities shall be determined using one of the methods in Section XIII, 9.7.4 through 9.7.6.

8.2 SECTION VIII, DIVISION 1 – OVERPRESSURE PROTECTION REQUIREMENTS FOR PRESSURE VESSELS

All Section VIII, Division 1 pressure relief device requirements have been transferred from Paragraphs UG-125 through UG-140 to Section XIII – Rules for Overpressure Protection, and the remaining Division 1 overpressure protection requirements have been restructured within the new Paragraphs UG-150 through UG-156. See Nonmandatory Appendix PP – Guide to the Relocation of Overpressure Protection Requirements in Section VIII, Division 1 for a complete cross-reference list. Table PP-1-1 in Nonmandatory Appendix PP lists the new locations for all requirements formerly located in UG-125 through UG-140.

Paragraph UG-150 – General Requirements states: *(a)* UG-150 through UG-155 provide the acceptable methods and requirements for overpressure protection for pressure vessels constructed to the requirements of this Division. Acceptable methods include pressure relief devices, open flow paths, and overpressure protection by system design. Paragraph UG-150 specifies the type, quantity and settings of acceptable pressure relief devices and relieving capacity requirements including maximum allowed relieving pressures.

Paragraph UG-153 – Overpressure Limits states: *(a)* Other than unfired steam boilers, when a pressure relief device is provided, it shall prevent the pressure from rising more than 10% or 3 psi (20 kPa), whichever is greater, above the maximum allowable working pressure, except as permitted in (1) and (2) and UG-54*(c)*. [See UG-155 for pressure settings.]

(1) When multiple pressure relief devices are provided and set in accordance with UG-155*(a)*, they shall prevent the pressure from rising more than 16% or 4 psi (30 kPa), whichever is greater, above the maximum allowable working pressure.

(2) When a pressure vessel can be exposed to fire or other unexpected sources of external heat, the pressure relief device(s) shall be capable of preventing the pressure from rising more than 21% above the maximum allowable working pressure. Supplemental pressure relief devices shall be installed to protect against this source of excessive pressure if the pressure relief devices used to satisfy the capacity requirements of *(a)* and *(1)* above have insufficient capacity to provide the required protection. See Nonmandatory Appendix M, M-13 for cases where the metal temperature due to fire or other sources of external heat can cause vessel failure prior to reaching the MAWP.

Paragraph UG-154 – Permitted Pressure Relief Devices and Methods provides requirements for protection against overpressure in accordance with the following paragraph.

(a) Pressure Relief Valves

(b) Nonreclosing Pressure Relief Devices

(c) Combination of Devices

(d) Open Flow Paths

(e) Overpressure Protection by System Design (Note: The 2007 edition of Section VIII, Division 1 does not includes rule for overpressure protection by system design.)

Paragraph UG-154*(e)* states that overpressure protection by system design in accordance with Section XIII, Part 13 is permitted under the following conditions.

- For vessels with overpressure protection by system design where the pressure is self-limited at or below the vessel MAWP, (see Section XIII, 13.2), there shall be no credible overpressure scenario in which the pressure exceeds the maximum allowable working pressure (MAWP) of the pressurized equipment at the coincident temperature.

- For vessels with overpressure protection by system design where the pressure is not self-limited at or below the vessel MAWP, (see Section XIII, 13.3):
  a. there shall be no credible overpressure scenario in which the pressure exceeds 116% of the MAWP times the ratio of the allowable stress value at the temperature of the overpressure scenario to the allowable stress value at the vessel design temperature.
  b. the overpressure limit shall not exceed the vessel test pressure.

8.3 SECTION VIII, DIVISION 2 – OVERPRESSURE PROTECTION REQUIREMENTS FOR PRESSURE VESSELS

All Section VIII, Division 2 pressure relief device requirements have been transferred from Part 9 – Pressure Vessel Overpressure Protection to Section XIII – Rules for Overpressure Protection and the remaining Division 2 overpressure protection requirements have been restructured within Part 9. Annex 9-B – Guide to the Relocation of Overpressure Protection Requirements provides a complete cross-reference list in Table 9-B.1-1 – Cross-Reference List. This table lists the new locations for all the affected requirements in the 2021 edition of Section VIII, Division 2 of the ASME BPVC. Annex 9-B will be deleted from the next edition of this Division.

Paragraph 9.1 – General Requirements states: *(a)* Part 9 provides the acceptable methods and requirements for overpressure protection for pressure vessels constructed to the requirements of this Division. Acceptable methods include pressure relief devices, open flow paths, and overpressure protection by system design (Note: The 2007 edition of Section VIII, Division 2 includes rule for overpressure protection by system design in Paragraph 9.7 – Overpressure Protection by Design). Requirements in Part 9 establishes the type, quantity and settings of acceptable pressure relief devices, and relieving capacity requirements including maximum allowed relieving pressures. Unless otherwise specified, the required pressure relief devices shall be constructed, capacity certified, and bear the ASME Certification Mark in accordance with requirements provided in Section XIII. In addition, Part 9 provides requirements for installation of pressure relief devices.

Overpressure limits specified in Paragraph 9.4 provide requirements for preventing pressure vessels that conform to Section VIII, Division 2 rules from exceeding unacceptable pressure levels above MAWP while in service. According to these requirements, when a pressure relief device is provided, it shall prevent the pressure from rising more than 10% or 3 psi (20 kPa), whichever is greater, above the MAWP, except as permitted below.

1. When multiple pressure relief devices are provided and set in accordance with 9.6*(a)*, they shall prevent the pressure from rising more than 16% or 4 psi (30 kPa), whichever is greater, above MAWP.
2. When a pressure vessel can be exposed to fire or other unexpected sources of external heat, the pressure relief device(s) shall be capable of preventing the pressure from rising more than 21% above the maximum allowable working pressure.
3. The aggregate capacity of the open flow paths, or vents, shall be sufficient to prevent overpressure in excess of those specified in 1 and 2 above.
4. When the MAWP is 15 psi (105 kPa) or less, in no case shall the pressure be allowed to rise more than 21% above the MAWP.

Guidance to accommodate loadings produced by deflagration are provided in Annex 4-D in the 2021 edition of Section VIII, Division 2 of the ASME BPVC.

Paragraph 9.5 – Permitted Pressure Relief Devices and Methods states that protection against overpressure shall be provided by pressure relief devices, open flow paths or system design, or a combination. Paragraph 9.5*(e)* permits protection by system design in accordance with requirements provided in Section XIII, Part 13 as follows.

- For pressure vessels with overpressure protection by system design where the pressure is self-limited at or below the vessel MAWP, (see Section XIII, 13.2), there shall be no credible overpressure scenario in which the pressure exceeds the MAWP of the pressurized equipment at the coincident temperature.
- For pressure vessels with overpressure protection by system design where the pressure is not self-limited at or below the vessel MAWP (see Section XIII, 13.3), there shall be no credible overpressure scenario in which the pressure exceeds 116% of the MAWP times the ratio of the allowable stress value at the temperature of the overpressure scenario to the allowable stress value at the vessel design temperature. The overpressure limit shall not exceed the vessel test pressure.

9. TECHNICAL RATIONALE FOR EQUIVALENT SAFETY

The equivalent safety evaluations documented in Sects. 9.1 through 9.10 of this report provide information needed to determine if rules specified in the 2021 edition of the ASME BPVC provide an equivalent level of safety to the corresponding rules specified in the 2007 edition of the ASME BPVC. These equivalent safety evaluations are organized by rules and requirements and subdivided into the following categories.

- Evaluation of equivalent safety for rules and requirements specified in the 2021 edition of ASME BPVC Construction Codes compared to correspond rules and requirements specified in the 2007 edition of these ASME BPVC Construction Codes:
  1. Section I
  2. Section VIII, Division 1
  3. Section VIII, Division 2
- Evaluation of equivalent safety for rules and requirements revised or added to the 2021 edition of ASME BPVC Construction and Reference Codes:
  1. Section I
  2. Section II
  3. Section V
  4. Section VIII, Division 1
  5. Section VIII, Division 2
  6. Section IX
  7. Section XIII

Each of these equivalent safety evaluation categories includes a summary of technical rationale used as the basis for the equivalent safety evaluation and references to the sections of this report that provides supporting information. A discussion of the analysis methods used to evaluate equivalent safety is presented in Sect. 1.4 of this report.

9.1 EQUIVALENT SAFETY EVALUATION OF RULES AND REQUIREMENTS SPECIFIED IN THE 2007 AND 2021 EDITIONS OF SECTION I OF THE ASME BPVC

Table 9.1 of this report documents equivalent safety evaluations for rules and requirements specified in the 2021 edition of Section I – Rules for Construction of Power Boilers compared to correspond rules and requirements specified in the 2007 edition of Section I of the ASME BPVC.

9.2 EQUIVALENT SAFETY EVALUATION OF RULES AND REQUIREMENTS SPECIFIED IN THE 2007 AND 2021 EDITIONS OF SECTION VIII, DIVISION 1 OF THE ASME BPVC

Table 9.2 of this report documents equivalent safety evaluations for rules and requirements specified in the 2021 edition of Section VIII, Division 1 – Rules for Construction of Pressure Vessels compared to correspond rules and requirements specified in the 2007 edition of Section VIII, Division 1 of the ASME BPVC.

9.3 EQUIVALENT SAFETY EVALUATION OF RULES AND REQUIREMENTS SPECIFIED IN THE 2007 AND 2021 EDITIONS OF SECTION VIII, DIVISION 2 OF THE ASME BPVC

Table 9.3 of this report documents equivalent safety evaluations for rules and requirements specified in the 2021 edition of Section VIII, Division 2 – Rules for Construction of Pressure Vessels – Alternative Rules of compared to correspond rules and requirements specified in the 2007 edition of Section VIII, Division 2 of the ASME BPVC.

9.4 EQUIVALENT SAFETY EVALUATION OF RULES AND REQUIREMENTS REVISED OR ADDED TO THE 2021 EDITION OF SECTION I OF THE ASME BPVC

Table 9.4 of this report documents equivalent safety evaluations for rules and requirements revised or added to the 2021 edition of Section I – Rules for Construction of Power Boilers of the ASME BPVC.

9.5 EQUIVALENT SAFETY EVALUATION OF RULES AND REQUIREMENTS REVISED OR ADDED TO THE 2021 EDITION OF SECTION II OF THE ASME BPVC

Table 9.5 of this report documents equivalent safety evaluations for rules and requirements revised or added to the 2021 edition of Section II – Materials of the ASME BPVC.

9.6 EQUIVALENT SAFETY EVALUATION OF RULES AND REQUIREMENTS REVISED OR ADDED TO THE 2021 EDITION OF SECTION V OF THE ASME BPVC

Table 9.6 of this report documents equivalent safety evaluations for rules and requirements revised or added to the 2021 edition of Section V – Nondestructive Examination of the ASME BPVC.

9.7 EQUIVALENT SAFETY EVALUATION OF RULES AND REQUIREMENTS REVISED OR ADDED TO THE 2021 EDITION OF SECTION VIII, DIVISION 1 OF THE ASME BPVC

Table 9.7 of this report documents equivalent safety evaluations for rules and requirements revised or added to the 2021 edition of Section VIII, Division 1 – Rules for Construction of Pressure Vessels of the ASME BPVC.

9.8 EQUIVALENT SAFETY EVALUATION OF RULES AND REQUIREMENTS REVISED OR ADDED TO THE 2021 EDITION OF SECTION VIII, DIVISION 2 OF THE ASME BPVC

Table 9.8 of this report documents equivalent safety evaluations for rules and requirements revised or added to the 2021 edition of Section VIII, Division 2 – Rules for Construction of Pressure Vessels – Alternative Rules of the ASME BPVC.

9.9 EQUIVALENT SAFETY EVALUATION OF RULES AND REQUIREMENTS REVISED OR ADDED TO THE 2021 EDITION OF SECTION IX OF THE ASME BPVC

Table 9.9 of this report documents equivalent safety evaluations for rules and requirements revised or added to the 2021 edition of Section IX – Welding, Brazing, and Fusing Qualifications of the ASME BPVC.

9.10 EQUIVALENT SAFETY EVALUATION OF RULES AND REQUIREMENTS REVISED OR ADDED TO THE 2021 EDITION OF SECTION XIII OF THE ASME BPVC

Section XIII – Rules for Overpressure Protection of the ASME BPVC was added to the 2021 edition as discussed in Sect. 2.8 of this report. This new Section XIII is not intended to provide any new technical requirements from 2019. Therefore, an equivalent safety evaluation of the rules and requirements in Section XIII was not performed.

Table 9.1 Evaluation of equivalent safety for rules and requirements specified in the 2021 edition of Section I compared to correspond rules and requirements specified in the 2007 edition of Section I of the ASME BPVC

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
4.1.1.1	Excessive Elastic Deformation and Elastic Instability	Excessive elastic deformation (deflection) and elastic instability (buckling) cannot be controlled by imposing upper limits to the calculated stress alone because these behavioral phenomena are affected by component geometry and stiffness and material properties. Excessive elastic deformation can occur when a component with inadequate stiffness experiences unwanted flexibility or unacceptable deflections. Buckling is characterized by a sudden sideways failure of a component subjected to high compressive stress, where the compressive stress at the point of failure is less than the ultimate compressive stress that the material is capable of withstanding. The designer of a boiler or pressure vessel is responsible for applying engineering principles to understand and avoid in-service problems or failures caused by excessive elastic deformation and elastic instability. Charts and tables for determining shell thickness of components under external pressure that are designed and fabricated in accordance with rules specified in Section I of the ASME BPVC are provided in Subpart 3 in the 2007 and 2021 editions of Section II, Part D, of ASME BPVC. The basis for establishing external pressure charts in Subpart 3 is discussed in Mandatory Appendix 3. According to Mandatory Appendix 3, Paragraph 3-100 in the 2007 and 2021 editions of Section II, Part D, of ASME BPVC: The charts in Subpart 3 were established in order to facilitate a conservative approach in determining external pressure ratings for components covering a wide range of geometries, materials, and conditions. The methods provide for a uniform basis of calculation for the referencing Section; the use of the charts eliminates the need for complex calculations by equations and incorporates realistic factors of safety for components of widely varying length-to-diameter and diameter-to-thickness ratios. In addition, Section I, Paragraph PG-29.9 in the 2007 and 2021 editions of the ASME BPVC state that unstayed dished heads with the pressure on the convex side must have a maximum allowable working pressure equal to 60% of that for heads of the same dimensions with the pressure on the concave side. To further address excessive elastic deformation and elastic instability for components under external pressure, Section I, Paragraph PG-28 of the 2021 edition of the ASME BPVC expands rules for components under external pressure as discussed in Sect. 4.1.1.1 of this report.	Excessive elastic deformation and elastic instability requirements in the 2021 edition provide equivalent safety compared to excessive elastic deformation and elastic instability requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
4.1.2	Excessive Plastic Deformation	The plastic deformation mode of failure (ductile rupture) is controlled by imposing limits on calculated stress. Primary stress limits and primary plus secondary stress limits specified in the ASME BPVC are intended to prevent excessive plastic deformation leading to incremental collapse and to provide a nominal margin on the ductile burst pressure. The designer of a boiler or pressure vessel is responsible for ensuring that the specified stress limits are not exceeded under the operating conditions defined by the user. There are no rules specified in Section I of the ASME BPVC specifically for protection against plastic collapse. However, as discussed in Sect. 2.4.2 of this report, the maximum allowable membrane stress, P_m, for boilers constructed in accordance with rules specified in the 2007 and 2021 editions of Section I of the ASME BPVC is limited to two-thirds of the yield strength, $2/3S_y$, or less. This limit provides a minimum design margin against plastic collapse equal to or greater than 1.5, provides protection against plastic collapse, and prevents excessive plastic deformation by ensuring elastic response to all operating conditions. Additional discussion about protection against plastic collapse is presented in Sect. 4.8.1 of this report.	Excessive plastic deformation requirements in the 2021 edition provide equivalent safety compared to excessive plastic deformation requirements in the 2007 edition.
4.1.3.1	Brittle Fracture	The ability of a metal to resist tearing or cracking is a measure of its fracture toughness. In fracture mechanics calculations, the value of the stress intensity factor, K_I, is based on the applied stress and dimensions of the flaw. To avoid brittle fracture, the calculated K_I must be less than the critical fracture toughness parameter, K_{Ic}. From an equivalency viewpoint, an increase in the maximum allowable design stress for a material with a critical flaw size requires an increase in fracture toughness to maintain the same margin against brittle fracture. In addition, increasing fracture toughness reduces the risk that critical flaw sizes below the NDE detection limits do not result in brittle fracture. Boilers that are designed and fabricated in accordance with rule specified in Section I of the ASME BPVC operate at elevated temperatures where brittle fracture is a very unlikely mode of failure. Therefore, no fracture toughness requirements are provided in either the 2007 or the 2021 edition of Section I of the ASME BPVC.	Requirements in the 2021 edition for protection against brittle fracture provide equivalent safety compared to requirements in the 2007 edition for protection against brittle fracture.
4.1.4.1	Stress Rupture and Creep Deformation	Boiler and pressure vessel materials that are in service above a certain temperature undergo continuing deformation (creep) at a rate that is strongly influenced by both stress and temperature. The temperature at which creep occurs varies with the alloy composition. To prevent excessive deformation and possible premature rupture it is necessary to limit the allowable stresses by additional criteria on creep-rate and stress-rupture.	Stress rupture and creep deformation requirements in the 2021 edition provide equivalent safety compared to stress rupture and creep

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
		Criteria for establishing allowable stress values for Tables 1A and 1B are provided in Mandatory Appendix 1, Table 1-100 in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC. Allowable stress values in Tables 1A and 1B apply to materials permitted for boiler construction. These criteria, which are discussed in Sect. 4.4.1 of this report, cover temperatures in the range where creep and stress rupture strength govern the selection of stresses. The criteria for establishing allowable stress values provided in Mandatory Appendix 1, Table 1-100 in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC are the same. Section I, Paragraph PG-5 in the 2021 edition of the ASME BPVC allow P-No. 15E, Group 1 materials for boiler construction. Further discussions about P-No. 15E, Group 1 materials are presented in Sect. 5.3.1 of this report.	deformation requirements in the 2007 edition.
4.1.5.1	Plastic Instability – Incremental Collapse	Ratcheting is defined as a progressive incremental inelastic deformation or strain that can occur in a component subjected to variations of mechanical stress, thermal stress, or both. Ratcheting is produced by a sustained load acting over the full cross section of a component, in combination with a strain controlled cyclic load or temperature distribution that is alternately applied and removed. Ratcheting results in cyclic straining of the material, which can result in failure by fatigue and at the same time produces cyclic incremental deformation of a component, which may ultimately lead to collapse. Boilers that are designed and fabricated in accordance with rule specified in Section I of the ASME BPVC are generally not subjected to cyclic loading. Therefore, no plastic instability and incremental collapse requirements associated with ratcheting are specified in either the 2007 or the 2021 edition of Section I of the ASME BPVC.	Plastic instability and incremental collapse requirements in the 2021 edition provide equivalent safety compared to plastic instability and incremental collapse requirements in the 2007 edition.
4.1.6.1	Fatigue	Fatigue is the weakening of a material caused by repeatedly applied loads. It is the progressive and localized material degradation that occurs when a component is subjected to cyclic loading. If the loads are above a certain threshold, microscopic cracks will begin to form at stress concentrations such as square holes or sharp corners. Eventually the crack will reach a critical size, propagate, and cause the component to fracture. Avoidance of discontinuities that increase local stresses will increase the fatigue life of a component subjected to cyclic loading. Boilers that are designed and fabricated in accordance with rule specified in Section I of the ASME BPVC are generally not subjected to cyclic loading. In addition, rules specified in the 2007 and 2021 editions of Section I of the ASME BPVC do not: • require calculation of thermal stresses and do not provide allowable values for them	Fatigue requirements in the 2021 edition provide equivalent safety compared to fatigue requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
		• require the detailed calculation and classification of all stresses and the application of different stress limits to different classes of stress • consider the possibility of fatigue failure [6] Instead, rules in the 2007 and 2021 editions of Section I of the ASME BPVC provide equations for minimum wall thickness based on the maximum stress theory discussed in Sect. 4.5.1 of this report. Therefore, no fatigue requirements are provided in either the 2007 or the 2021 edition of Section I of the ASME BPVC.	
4.1.7.1	Stress Corrosion and Corrosion Fatigue	Two common types of corrosion that can adversely affect the integrity of a boiler or pressure vessel include stress corrosion cracking and corrosion fatigue. Stress corrosion cracking (SCC) is the growth of crack formation in a corrosive environment and is highly chemically specific in that certain alloys are likely to undergo SCC only when exposed to a small number of chemical environments. Corrosion fatigue is the mechanical degradation of a material under the combined action of corrosion and cyclic loading. Since corrosion-fatigue cracks initiate at a metal's surface, surface treatments like plating, cladding, nitriding, and shot peening can improve the materials' resistance to corrosion fatigue. However, corrosion fatigue only occurs when the metal is under tensile stress. Concerns for corrosion of certain materials used for boiler construction are identified in the following statement in Paragraph PG 5.5 in the 2007 and 2021 editions of Section I of the ASME BPVC which states: Austenitic alloys are susceptible to intergranular corrosion and stress corrosion cracking when used in boiler applications in water-wetted service. Factors that affect the sensitivity to these metallurgical phenomena are (1) applied or residual stress and (2) water chemistry. Susceptibility to attack is usually enhanced by using the material in a stressed condition with a concentration of corrosive agents (e.g., chlorides, caustic, or reduced sulfur species). For successful operation in water environments, residual and applied stresses must be minimized and careful attention must be paid to continuous control of water chemistry. However, the 2007 and 2021 editions of Section I of the ASME BPVC do not include rules that specifically govern corrosion allowances.	Stress corrosion cracking and corrosion fatigue requirements in the 2021 edition provide equivalent safety compared to stress corrosion cracking and corrosion fatigue requirements in the 2007 edition.
4.2.1	Design Basis	Requirements defined in Paragraph PG-22 – Loadings in the 2007 and 2021 editions in Section I of the ASME BPVC state that the stresses due to hydrostatic head shall be taken into account in determining the minimum thickness required unless noted otherwise. This Section does not fully address additional loadings other than those from working pressure or static head. Consideration shall be given to such additional loadings.	Design basis requirements in the 2021 edition provide equivalent safety compared to design basis requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
		This requirement ensures that post-construction loads such as those associated with in-service pressure tests that may be imposed by PHMSA regulations or by the Authority Having Jurisdiction are included in the design basis.	
4.4.1	Allowable Stress Values	Allowable stresses for materials permitted for boiler construction are specified in Tables 1A and 1B in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC. Criteria for establishing allowable stress values for Tables 1A and 1B are provided in Mandatory Appendix 1, Table 1-100 in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC. According to these criteria, the maximum allowable stress values in Tables 1A and 1B is either two-thirds of the specified minimum yield strength at room temperature or the ultimate tensile strength divided by 3.5, whichever is less. Based on these criteria, the yield strength controls the allowable stress when the ultimate tensile strength of the material is greater than 2.33 (e.g., 2/3 × 3.5) times the yield strength. These criteria ensure a minimum design margin of 1.5 against plastic collapse as discussed in Sect. 4.4.1 of this report.	Allowable stress rules in the 2021 edition provide equivalent safety compared to allowable stress rules in the 2007 edition.
4.5.1	Strength Theory	Equations specified in the 2007 and 2021 editions of Section I of the ASME BPVC for determining wall thickness are, by implication, consistent with the maximum stress theory discussed in Sect. 4.5.1 of this report.	The strength theory used as the basis for equations in the 2021 edition is equivalent in safety to the strength theory used as the basis for equations in the 2007 edition.
4.7	Stress Range for Repetitively Applied Loads	Shakedown of a component occurs if, after a few cycles of load application, ratcheting ceases. The subsequent structural response is elastic or elastic-plastic, and progressive incremental inelastic deformation is absent. Elastic shakedown is the case in which the subsequent response is elastic. Section I of the ASME BPVC does not consider the possibility of fatigue failure. Therefore, Section I of the ASME BPVC does not include rules for the 'shakedown' phenomenon.	An equivalent safety evaluation of rules in the 2007 and 2021 editions for repetitively applied loads is not possible.
4.8.1	Plastic Collapse Stress Limits	Plastic collapse is the load at which overall structural instability occurs. The collapse load is the maximum load limit for a component made of elastic perfectly plastic material. Deformations of these components increase without bound at the collapse load. Adequate safety against plastic collapse for boilers constructed in accordance with rules specified in the 2007 and 2021 editions of Section I is achieved by limiting design membrane stress, P_m, to two-thirds of the yield strength to be consistent with the maximum stress theory discussed in Sect. 4.4.1 of this report.	Allowable stress rules in the 2021 edition provide equivalent safety to allowable stress rules in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
		Rules specified in the 2007 and 2021 editions of Section I of the ASME BPVC do not require a detailed stress analysis to evaluate protection against plastic collapse but merely set the wall thickness necessary to keep the basic hoop stress below the tabulated allowable stress. As discussed in Sect. 4.4.1 of this report of this report, the maximum allowable stress for boilers constructed in accordance with rules specified in Section I is limited to two-thirds of the yield strength, $2/3\ S_y$, or less. Based on the principles of limit design theory discussed in Sect. 2.4.2 of this report, the minimum design margin against plastic collapse is at least 1.5.	
4.9.1	Design-by-Rule	The design approach used in the 2007 and 2021 editions of Section I of the ASME BPVC is referred to as design-by-rule. This design-by-rule approach is not based on detailed stress analysis. Instead, design-by-rule generally involves calculation of average membrane stress across the thickness of the walls of the component. As discussed in Sect. 4.5.1 of this report, rules in the 2007 and 2021 editions of Section I are based on the maximum stress theory. Rules for openings and compensation are specified in Paragraphs PG-32 through PG-39 in the 2007 and 2021 editions of Section I of the ASME BPVC. These rules are based on the area replacement concept in which the metal cut out by an opening must be replaced by reinforcement within a prescribed zone around the opening.	The design-by-rule approach in the 2021 edition provides equivalent safety to the design-by-rule approach in the 2007 edition
4.10	Design-by-Analysis	The 2007 and 2021 editions of Section I of the ASME BPVC do not include design-by-analysis requirements.	An equivalent safety evaluation of design-by-analysis requirements in the 2007 and 2021 editions is not possible.
5.1.1	Forming Deviations	Paragraph PG-80 – Permissible Out-Of-Roundness of Cylindrical Shells in the 2007 and 2021 editions of Section I of the ASME BPVC provides requirements for out-of-roundness of cylindrical shells subjected to internal and external pressure. The requirements are applicable to finished cylindrical sections of headers, shells, drums, and similar components subjected to internal pressure, and welded cylindrical furnaces and other cylindrical parts subjected to external pressure. The out-of-roundness requirements are the same in 2007 and 2021 editions.	Forming deviations in the 2021 edition provide equivalent safety to forming deviations in the 2007 edition.
5.2.1.1	Formed Head Tolerances	The same shape deviation requirements for formed heads are specified in Paragraph PG-81 in the 2007 and 2021 editions of Section I of the ASME BPVC. The rule in Paragraph PG-81 in both editions states that when heads are made to an approximate ellipsoidal shape, the inner surface of such heads must lie outside and not inside of a true ellipse drawn with the major axis equal to the inside diameter of the head and one-half the minor axis equal to the depth of the head. The	Formed head tolerances in the 2021 edition provide equivalent safety to formed head

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
		maximum variation from this true ellipse shall not exceed 0.0125 times the inside diameter of the head.	tolerances in the 2007 edition.
5.2.2.1	Alignment Tolerances	Table PW-33 – Alignment Tolerance of Sections to be Butt Welded in Paragraph PW-33 – Alignment Tolerance, Shells and Vessels (Including Pipe or Tube Used as a Shell) in the 2007 and 2021 editions of Section I of the ASME BPVC specifies alignment tolerance for sections to be butt welded. The alignment tolerance provided in Table PW-33 are the same in 2007 and 2021 editions.	Alignment tolerances in the 2021 edition provide equivalent safety to alignment tolerances in the 2007 edition.
5.3.1	Base Metal Groupings	P-Numbers are assigned to base metals for the purpose of reducing the number of required welding and brazing procedure qualifications. P-Numbers for the same base metal are different for welding and brazing. Paragraph PG-5.6 in Section I of the 2021 edition of the ASME BPVC specifies rules that permit use of P-No. 15E, Group 1 materials for boiler construction. Section I in the 2007 edition of the ASME BPVC did not include Paragraph PG-5.6 (see Paragraph PG-5 in Table 9.2 of this report).	P-Numbers in the 2021 edition provide equivalent safety to P-Numbers in the 2007 edition.
5.3.2	Welding and Brazing Methods in Section IX	Rules for welding and brazing are specified in Part QW and Part QB, respectively, in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for plastic fusing are only specified in Part QF in the 2021 edition of Section IX of the ASME BPVC. All of the welding and brazing methods permitted in the 2007 edition are also permitted in the 2021 edition. However, Diffusion Welding (DFW), Low-Power Density Laser Beam Welding (LLBW), and Friction Stir Welding (FSW) are also permitted in the 2021 edition.	Welding and brazing methods in the 2021 edition provide equivalent safety to welding and brazing methods in the 2007 edition. Fusing method rules are not specified in the 2007 edition.
5.3.3	Rules in Section IX for Procedure Specification	A Procedure Specification addresses the conditions (including ranges, if any) under which the material joining process must be performed. These conditions are referred to as “variables.” When a Procedure Specification is prepared by the organization, it must address, as a minimum, the specific essential and nonessential variables that are applicable to the material joining process to be used in production. When toughness qualification of the material joining procedure is required, the applicable supplementary essential variables must also be addressed in the Procedure Specification. Rules for welding procedure qualification are specified in Part QW, Article II in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for brazing procedure qualification are specified	Procedure specification rules in the 2021edition provide equivalent safety to procedure specification rules in the 2007 edition. Procedure specification rules for fusing are not

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
		in Part QB, Article XII in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for plastic fusing procedure qualification are only specified in Part QF, Article XXII in the 2021 edition of Section IX of the ASME BPVC.	specified in the 2007 edition.
5.3.4	Rules in Section IX for Procedure Qualification Record (PQR)	The Procedure Qualification Record (PQR) documents what occurred during the production of a procedure qualification test coupon and the results of testing that coupon. As a minimum, the record must document the essential variables for each process used to produce the test coupon, the ranges of variables qualified, and the results of the required testing and nondestructive examinations. The organization must certify a PQR by a signature or other means as described in the organization's Quality Control System and must make the PQR accessible to the Authorized Inspector. Rules that govern PQR are specified in Paragraph QW-200.2 for welding and QB-200.2 for brazing in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules that govern PQR for plastic fusing are specified in Paragraph QF-201.5 for in the 2021 edition of Section IX of the ASME BPVC.	Procedure qualification record rules in the 2021 edition provide equivalent safety to procedure qualification record rules in the 2007 edition.
5.3.5	Rules in Section IX for Performance Qualification	The purpose of qualifying the person who will use a joining process is to demonstrate that person's ability to produce a sound joint when using a Procedure Specification. Rules for welding performance qualification are specified in Part QW, Article III in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for brazing performance qualification are specified in Part QB, Article XIII in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for plastic fusing performance qualification are only specified in Part QF, Article XXIII in the 2021 edition of Section IX of the ASME BPVC.	Performance qualification rules in the 2021 edition provide equivalent safety to performance qualification rules in the 2007 edition. Performance qualification rules for fusing are not specified in the 2007 edition.
5.3.6	Rules in Section IX for Performance Qualification Record	The performance qualification record documents what occurred during the production of a test coupon by a person using one or more joining processes following an organization's Procedure Specification. As a minimum, the record shall document: *(a)* the essential variables for each process used to produce the test coupon *(b)* the ranges of variables qualified as required by the applicable part (see QW-301.4, QB-301.4, and QF-301.4) *(c)* the results of the required testing and nondestructive examinations	Performance qualification record rules in the 2021 edition provide equivalent safety to performance qualification record rules in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
		(d) the identification of the procedure specification(s) followed during the test Rules for Welder/Welding Operator Performance Qualification (WPQ) are specified in Paragraph QW-301.4 in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for Brazer or Brazing Operator Performance Qualification (BPQ) are specified in Paragraph QB-301.4 in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for Fusing Operator Performance Qualification Record (FPQ) are specified in Paragraph QF-301.4 in the 2021 edition of Section IX of the ASME BPVC.	Performance qualification record rules for fusing are not specified in the 2007 edition.
5.3.7	Rules in Section IX Welding, Brazing, and Fusing Data	Welding, brazing, and fusing data articles include the variables grouped into categories such as joints, base materials and filler materials, positions, preheat and postweld heat treatment, gas, electrical characteristics, and technique. These variables are referenced from other articles as they apply to each process. Welding data include essential, supplementary essential, or nonessential variables. Brazing data include essential and nonessential variables. Fusing data include the fusing variables grouped as joints, pipe material, position, thermal conditions, equipment, and technique. Rules for welding data are specified in Part QW, Article IV in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for brazing data are specified in Part QB, Article XIV in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for fusing data are only specified in Part QF, Article XXIV in the 2021 edition of Section IX of the ASME BPVC.	Welding and brazing, data rules in the 2021 edition provide equivalent safety to welding and brazing, data rules in the 2007 edition. Fusing data rules are not specified in the 2007 edition.
5.4.1.1	Preheating Requirements	Preheat temperature is defined as the minimum temperature in the weld joint preparation immediately prior to the welding; or in the case of multiple pass welds, the minimum temperature in the section of the previously deposited weld metal, immediately prior to welding. Preheating requirements for welding are specified in Article IV – Welding Data Paragraph QW-406 in the 2007 and 2021 editions of the ASME BPVC. The WPS for the material being welded specifies the minimum preheating requirements in accordance with the weld procedure qualification requirements of Section IX that apply to construction of boilers in accordance with rules specified in Section I of the ASME BPVC.	Preheating rules in the 2021 edition provide equivalent safety to preheating rules in the 2007 edition.
5.4.2.1	Postweld Heat Treatment Requirements	Requirements for postweld heat treatment are specified in Paragraph PW-39 – Requirements for Postweld Heat Treatment in the 2007 and 2021 editions of Section I of the ASME BPVC. According to requirements specified in Paragraph PW-39.1, all welded pressure parts of power boilers must be given a postweld heat treatment at a minimum hold temperature not less than that specified in Table PW-39 in the 2007 edition or Tables PW-39-1 through PW-39-14 in the 2021 edition.	Postweld heat treatment rules in the 2021 edition provide equivalent safety to postweld heat treatment

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
			rules in the 2007 edition.
5.5	Cold Stretching	The 2007 and 2021 editions of Section I of the ASME BPVC do not include cold stretching requirements.	An equivalent safety evaluation of cold stretching requirements in the 2007 and 2021 editions is not possible.
5.6.1	Quality Control System	Quality control system requirements are provided in Paragraph PG-105.4 in the 2007 and 2021 editions of Section I of the ASME BPVC. Paragraph PG-105.4 in the 2007 state that the quality control system shall be in accordance with the requirements of A-300. Whereas Paragraph PG-105.4 in the 2021 edition state: *Any Manufacturer or Assembler holding or applying for a Certificate of Authorization shall demonstrate a quality program that meets the requirements of ASME CA-1 and establishes that all Code requirements including material, design, fabrication, examination (by the Manufacturer), and inspection for boilers and boiler parts (by the Authorized Inspector) will be met. The quality control system shall be in accordance with the requirements of A-301 and A-302.* Publication ASME CA-1 [2], which was issued in 2020, specifies requirements for accreditation and certification of organizations supplying products or services that are intended to conform to the requirements of ASME standards listed in Table 1 – ASME Certification Programs. Publication ASME CA-1 was initially issued in 2013.	Quality control system requirements in the 2021 edition provide equivalent or greater safety to quality control system requirements in the 2007 edition.
6.2.1	General NDE Requirements	Rules for circumferential and longitudinal butt-welded joints in boilers that are fabricated by welding and require volumetric examination are specified in Paragraph PW-11 – Requirements for Boilers Fabricated by Welding in the 2007 and 2021 editions of Section I of the ASME BPVC. These rules state that all circumferential and longitudinal butt-welded joints must be examined throughout their entire length unless specifically exempted by rules that depend on the service conditions, nominal pipe size, or material thickness. Rules specified in Paragraph PW-11 further define which volumetric examination method (RT or UT) or combination of methods (RT and UT) must be used to examine particular types of circumferential and longitudinal butt-welded joints as discussed in Sects. 6.2.1.1 and 6.2.1.2 of this report.	General NDE requirements in the 2021 edition provide equivalent safety to general NDE requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
6.2.1.1	Radiographic Examination Requirements	Rules for radiography examination of welds are provided in Paragraph PW-51 – Radiographic Examination in the 2007 and 2021 editions of Section I of the ASME BPVC. These rules state that all welds that require radiographic examination must be examined by the X-ray or gamma-ray method in accordance with rules specified in Article 2 – Radiographic Examination, Section V of the ASME BPVC. Paragraphs PW-51.3.1 and PW-51.3.2 in both editions define the conditions under which indications shown on the radiographs of welds and characterized as imperfections are unacceptable and must be repaired and the repair radiographed.	Radiographic examination requirements in the 2021 edition provide equivalent safety to radiographic examination requirements in the 2007 edition.
6.2.1.2	Ultrasonic Examination Requirements	Rules for ultrasonic examination of welds are provided in Paragraph PW-52 – Ultrasonic Examination in the 2007 and 2021 editions of Section I of the ASME BPVC. The rules in Paragraph PW-52.1 state that technique and standards for ultrasonic examination shall follow Section V, Article 4. However, rules specified in Paragraph PW-52.1 in the 2021 edition further state that techniques and standards for ultrasonic examination must follow rules specified in Section V, Article 4, Mandatory Appendix VII – Ultrasonic Examination Requirements for a Workmanship Based Acceptance Criteria. As an alternative, Nonmandatory Appendix E – Alternative Method for Ultrasonic Examination may be used for the ultrasonic examination of welds requiring volumetric examination by PW-11 – Volumetric Examination of Welded Butt Joints.	Ultrasonic examination requirements in the 2021 edition provide equivalent safety to ultrasonic examination requirements in the 2007 edition.
6.2.1.3	Magnetic Particle Examination Requirements	Rules for magnetic particle examination of welds are provided in Paragraph PG-93 – Examination and Repair of Flat Plate in Corner Joints in the 2007 and 2021 edition of Section I of the ASME BPVC. Paragraph PG-93.3 states that methods and acceptance criteria for magnetic particle and liquid penetrant examination shall be in accordance with Paragraph A-260 in Nonmandatory Appendix A – Explanation of the Code Containing Matter Not Mandatory Unless Specifically Referred to in the Rules of the Code. Paragraph A-260 states that magnetic particle examination shall be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirement of T-150 of Section V.	Magnetic particle examination requirements in the 2021 edition provide equivalent safety to magnetic particle examination requirements in the 2007 edition.
6.2.1.4	Liquid Penetrant Examination Requirements	Procedures to be followed whenever liquid penetrant examination is required by rules specified in Section I are provided in Nonmandatory Appendix A in the 2007 and 2021 editions of Section I of the ASME BPVC. Paragraph A-270 states that detailed examination method of Section V, Article 6 – Liquid Penetrant Examination shall be used with the acceptance criteria specified in this appendix. Liquid penetrant examination shall be performed in accordance with a written procedure,	Liquid penetrant examination requirements in the 2021 edition provide equivalent safety to liquid penetrant

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
		demonstrated to the satisfaction of the Inspector, and certified by the Manufacturer to be in accordance with the requirement of T-150 of Section V.	examination requirements in the 2007 edition.
6.2.1.5	Visual Examination Requirements	Fabrication requirements specified in Paragraph PG-75 – General in the 2021 edition of Section I of the ASME BPVC states that unless otherwise required to verify compliance with specific parts of this Section, visual examination shall be performed to verify compliance with applicable requirements for dimensions, joint preparation, and alignment prior to welding or joining, and finished weld conditions. Corresponding requirements in Paragraph PG-75 are not specified in the 2007 edition of Section I of the ASME BPVC.	Visual examination requirements in the 2021 edition provide equivalent safety to visual examination requirements in the 2007 edition.
6.2.4.1	NDE Acceptance Standards	Acceptance standards provided in Section I for radiographic, ultrasonic, magnetic particle, and liquid penetrant examinations are compared in Tables 6.1 through 6.4 of this report. However, evaluation level requirements for ultrasonic examinations provided in Paragraph PW-52.3 in the 2021 edition are more comprehensive and clearly defined than the evaluation level requirements in the 2007 edition.	NDE acceptance standards in the 2021edition provide equivalent or greater safety to NDE acceptance standard in the 2007 edition.
6.2.4.4	Acceptance Criteria for Visual Examinations	Acceptance criteria for visual examinations are not provided in Section I of the ASME BPVC.	Acceptance criteria for visual examinations are not provided in Section I of the ASME BPVC.
6.2.5	Summary of Qualification and Certification Requirements for NDE Personnel	As discussed in Sect. 6.1 of this report, the Manufacturer is responsible for training, qualifying, and certifying of NDE personnel that perform NDE methods and evaluate NDE results. Requirements for qualification and certification for NDE personnel that are provided in Section I; Section VIII, Division 1; and Section VIII, Division 2 of the ASME BPVC are discussed in Sects. 6.2.1, 6.2.2, and 6.2.3 of this report, respectively. Table 6.6 is a crosswalk that maps paragraphs in Section I; Section VIII, Division 1; and Section VIII, Division 2 that provide qualification and certification requirements for NDE personnel to reference sections in this report where these qualification and certification requirements are examined and explained.	Certification requirement for NDE personnel in the 2021 edition provide equivalent safety to certification requirement for NDE personnel in the 2007 edition.
6.3.1	General NDE Requirements in Section V	Article 1 – General Requirements in the 2007 and 2021 editions of Section V of the ASME BPVC provide general requirements and methods for NDE which are Code requirements to the extent they are specifically referenced and required by a Construction Code or referencing documents. These	General NDE requirements in the 2021 edition provide equivalent safety to

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
		NDE methods are used to detect surface and internal imperfections in materials, welds, fabricated parts, and components. Rules for certification of nondestructive examination personnel are specified in Paragraphs T-120*(e)* and *(f)* in the 2021 edition of Section V of the ASME BPVC. These rules state: *(e) For those documents that directly reference this Article for the qualification of NDE personnel, the qualification shall be in accordance with their employer's written practice which shall be in accordance with one of the following documents:* *(1) SNT-TC-1A (2016 Edition), Personnel Qualification and Certification in Nondestructive Testing, as amended by Mandatory Appendix III; or* *(2) ANSI/ASNT CP-189 (2016 Edition), ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel, as amended by Mandatory Appendix IV* *(f) National or international central certification programs, such as the ASNT Central Certification Program (ACCP) or ISO 9712:2012-based programs, may be alternatively used to fulfill the training, experience, and examination requirements of the documents listed in (e) as specified in the employer's written practice.* By comparison, Paragraph T-120*(e)* in the 2007 edition of Section V of the ASME BPVC specifies the 2001 editions of SNT-TC-1A and ANSI/ASNT CP-189, and Paragraph T-120*(f)* in the 2007 edition of Section V of the ASME BPVC adds ISO 9712:2012-based programs as an example of a National or international central certification program. Addition rules for certification of NDE personnel are provided in Paragraphs T-120*(g)* and *(h)* in the 2021 edition of Section V of the ASME BPVC. These rules state: *(g) In addition to the requirements described in (e) or (f) above, if the techniques of computed radiography (CR), digital radiography (DR), phased-array ultrasonic (PAUT), ultrasonic time-of-flight diffraction (TOFD), or ultrasonic full matrix capture (FMC) are to be used, the training, experience, and examination requirements found in Article 1, Mandatory Appendix II shall also be included in the employer's written practice for each technique as applicable.* *(h) Alternatively, performance-based qualification programs, in accordance with ASME ANDE-1-2015, ASME Nondestructive Examination and Quality Control Central Qualification and Certification Program, may be used for training, experience, examination, and certification activities as specified in the written practice.*	general NDE requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
		The alternative rules for performance-based qualification programs permitted in Paragraphs T-120(*h*) in the 2021 edition of Section V are not included in the 2007 edition of Section V of the ASME BPVC.	
6.3.2	Radiographic Examination Requirements in Section V	Article 2 – Radiographic Examination in the 2007 and 2021 editions of Section V of the ASME BPVC provides requirements for radiographic examination of materials including castings and welds. The extent of radiographic examinations is as specified by the referencing Construction Code. Product-specific, technique-specific, and application-specific requirements are also provided in mandatory appendices provided in Section V, Article 2. Paragraph III-210 in Mandatory Appendix III in the 2007 and 2021 editions of Section V of the ASME BPVC states: *Digital image acquisition, display, and storage can be applied to radiography and radioscopy. Once the analog image is converted to digital format, the data can be displayed, processed, quantified, stored, retrieved, and converted back to the original analog format, for example, film or video presentation.* This requirement in Mandatory Appendix III only applies to digital image acquisition, display, and storage for radiography and radioscopy and not to digital radiography (DR) techniques as an alternative to film radiography. Rules in Paragraph IX-210 – Scope in Mandatory Appendix IX – Radiography Using Digital Detector Systems in the 2021 edition of Section V of the ASME BPVC specify requirements for the use of direct radiography (DR) techniques using digital detector systems (DDSs), where the image is transmitted directly from the detector rather than using an intermediate process for conversion of an analog image to a digital format. Mandatory Appendix IX also addresses applications in which the radiation detector, the source of the radiation, and the object being radiographed may or may not be in motion during exposure. Section V, Article 2 provisions apply unless modified by Mandatory Appendix IX. Radiography using digital detector systems as specified in Mandatory Appendix IX in the 2021 edition of Section V of the ASME BPVC is permitted as an alternative to digital image acquisition as provided in Mandatory Appendix III – Digital Image Acquisition, Display, and Storage for Radiography and Radioscopy in the 2007 and 2021 edition of Section V of the ASME BPVC. As noted above, the 2007 edition of Section V of the ASME BPVC does not include Mandatory Appendix IX – Application of Digital Radiography and Mandatory Appendix IX – Supplement A.	Radiographic examination requirements in Section V in the 2021 edition provide equivalent or greater safety to radiographic examination requirements in Section V in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
		Computed radiography (CR) and digital radiography (DR) are commonly used terms for digital radiographic detectors. Computed radiography uses a photostimulable storage phosphor that stores the latent image with subsequent processing using a stimulating laser beam and can be easily adapted to a cassette-based system analogous to that used in screen-film radiography. Historically, DR has been used to describe a digital X-ray imaging system that reads the transmitted X-ray signal immediately after exposure with the detector in place. Use of CR or DR provides equivalent or greater safety compared to use of film radiography and digital image acquisition provided NDE personnel are qualified and certified in the use of these methods. Rules for radiography examination of welds are provided in Paragraph PW-51 – Radiographic Examination in the 2007 and 2021 editions of Section I of the ASME BPVC. These rules state that all welds that require radiographic examination must be examined by the X-ray or gamma-ray method in accordance with rules specified in Article 2 – Radiographic Examination, Section V of the ASME BPVC.	
6.3.3	Ultrasonic Examination Requirements in Section V	Paragraph T-410 – Scope in Article 4 – Ultrasonic Examination Methods for Welds in the 2007 and 2021 editions of Section V of the ASME BPVC provides or references requirements for weld examinations. These requirements are used in selecting and developing ultrasonic examination procedures when examination to any part of this Article is a requirement of a referencing Code Section. These procedures are to be used for ultrasonic examinations and for dimensioning of indications for comparison with acceptance standards. Paragraph T-421 – Written Procedure Requirements states that ultrasonic examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table T-421 – Requirements of an Ultrasonic Examination Procedure or the Mandatory Appendices applicable to the technique in use. Product-specific, technique-specific, and application-specific requirements are also provided in the mandatory appendices in Section V, Article 4. Requirements provided in Article 4, Paragraph T-420 – General in the 2021 editions of Section V of the ASME BPVC were expanded from the 2007 edition to state: *The requirements of this Article shall be used together with Article 1, General Requirements. Refer to:* *(a) special provisions for coarse grain materials and welds in T-451* (provided in 2007 and 2021 editions) *(b) special provisions for computerized imaging techniques in T-452* (provided in 2007 and 2021 editions)	Ultrasonic examination requirements in Section V in the 2021 edition provide equivalent safety to ultrasonic examination requirements in Section V in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
		(c) Mandatory Appendix III for Time of Flight Diffraction (TOFD) techniques (provided in 2021 edition) *(d) Mandatory Appendix IV for phased array manual rastering techniques* (provided in 2021 edition) *(e) Mandatory Appendix V for phased array E-scan and S-scan linear scanning examination techniques* (provided in 2021 edition) *(f) Mandatory Appendix XI for full matrix capture (FMC) techniques* (provided in 2021 edition) Rules for ultrasonic examination of welds are provided in Paragraph PW-52 – Ultrasonic Examination in the 2007 and 2021 editions of Section I of the ASME BPVC. The rules in Paragraph PW-52.1 state that technique and standards for ultrasonic examination shall follow Section V, Article 4.	
6.3.4	Magnetic Particle Examination Requirements in Section V	Article 7 – Magnetic Particle Examination, Paragraph T-710 – Scope in the 2007 and 2021 editions of Section V of the ASME BPVC states that the magnetic particle examination techniques described in this Article must be used together with Article 1 – General Requirements when specified by the referencing Construction Code. Requirements in T-721 – Written Procedure Requirements states that magnetic particle examination shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table T-721 – Requirements of a Magnetic Particle Examination Procedure. Additional magnetic particle examination requirements are provided in the 2021 editions of Article 7, Section V of the ASME BPVC in the mandatory appendices. Nonmandatory Appendix A, Paragraph A-260 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC provides procedures that must be followed whenever magnetic particle examination is required by Paragraph PG-93. The detailed examination method of Section V, Article 7 – Magnetic Particle Examination must be used with the acceptance criteria specified in this appendix. Magnetic particle examination must be performed in accordance with a written procedure, demonstrated to the satisfaction of the Inspector, and certified by the Manufacturer to be in accordance with the requirement of Section V, Article 1 – General Requirements, T-150*(a)* or T-150*(b)*.	Magnetic particle examination requirements in Section V in the 2021 edition provide equivalent safety to magnetic particle examination requirements in Section V in the 2007 edition.
6.3.5	Liquid Penetrant Examination Requirements in Section V	Article 6 – Liquid Penetrant Examination, Paragraph T-610 – Scope in the 2007 and 2021 editions of Section V of the ASME BPVC states that when this Article is specified by a referencing Code Section, the liquid penetrant method described in Article 6 shall be used together with Article 1 – General Requirements. Requirements in Paragraph T-621 – Written Procedure Requirements states that liquid penetrant examination shall be performed in accordance with a written procedure which	Liquid penetrant examination requirements in Section V in the 2021 edition provide

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
		shall as a minimum, contain the requirements listed in Table T-621.1 – Requirements of a Liquid Penetrant Examination Procedure. Additional liquid penetrant examination requirements are provided in the mandatory appendices. Procedures to be followed whenever liquid penetrant examination is required by rules specified in Section I are provided in Nonmandatory Appendix A in the 2007 and 2021 editions of Section I of the ASME BPVC. Paragraph A-270 states that detailed examination method of Section V, Article 6 – Liquid Penetrant Examination shall be used with the acceptance criteria specified in this appendix.	equivalent safety to liquid penetrant examination requirements in Section V in the 2007 edition.
6.3.6	Eddy Current Examination Requirements in Section V	Article 8 – Eddy Current Examination in the 2007 and 2021 editions of Section V of the ASME BPVC states that the eddy current examination method and techniques described in this Article shall be used when specified by the referencing Code Section. Additional eddy current examination requirements are provided in the 2021 editions of Article 8, Section V of the ASME BPVC in the mandatory appendices. Rules for eddy current examinations are not specified either in the 2007 of the 2021 editions of Section I of the ASME BPVC.	Eddy current examination requirements in Section V in the 2021 edition provide equivalent safety to eddy current examination requirements in Section V in the 2007 edition.
6.3.7	Visual Examination Requirements in Section V	Article 9 – Visual Examination, Paragraph T-910 – Scope in the 2007 and 2021 editions of Section V of the ASME BPVC states that methods and requirements for visual examination in this Article are applicable together with requirements of Article 1 – General Requirements when specified by a referencing Construction Code. Specific visual examination procedures required for every type of examination are not included in this Article because there are many applications where visual examinations are required. The requirements of Article 1 – General Requirements, apply whenever visual examination, in accordance with Article 9 – Visual Examination, is required by a referencing Code Section. Requirements in T-921 – Written Procedure Requirements states that visual examinations shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table T-921 – Requirements of a Visual Examination Procedure. The 2007 and 2021 editions of Section I of the ASME BPVC do not require compliance with Article 9 – Visual Examination in Section V of the ASME BPVC.	Visual examination requirements in Section V in the 2021 edition provide equivalent safety to visual examination requirements in Section V in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
7.1.1.1	Basis for Hydrostatic Pressure Testing Limits	The objective of design rules specified in Section I of the ASME BPVC is to establish the wall thickness of a boiler so that the maximum hoop stress, P_m, does not exceed two third of the minimum specified yield strength, of the material, $P_m \leq 2/3S_y$. Hydrostatic pressure testing limits for boilers are specified in Paragraph PG-99 in the 2007 and 2021 editions of Section I of the ASME BPVC as follows. 2007 – minimum hydrostatic test pressure – 1.5 MAWP 2007 – maximum general membrane stress limit – $0.9P_m$ 2021 – minimum hydrostatic test pressure – 1.5 MAWP 2021 – maximum general membrane stress limit – $0.9P_m$ Overpressure protection rules specified in Paragraph PG-67.4.2 in the 2007 and 2021 editions of Section I of the ASME BPVC limit the pressure of an operating boiler, except for the steam piping between the boiler and the prime mover, to 1.20 MAWP or less. This overpressure protection limit ensures that the primary membrane stress, P_m, does not exceed $0.80S_y$ (i.e., $1.20/1.50$). A minimum hydrostatic test pressure equal to 1.5 MAWP or a membrane stress, P_m, equal to $0.90S_y$ ensures that the boiler will never experience a maximum overpressure while in service that is greater than the hydrostatic test pressure. (i.e., $0.9 \times 1.5\ \text{MAWP} > 1.20\ \text{MAWP}$) Rules specified in the 2007 and 2021 editions of Section I of the ASME BPVC do not specify a minimum or maximum hydrostatic test pressure duration. The rules state that a boiler must be maintained at the MAWP while the boiler is carefully examined.	Hydrostatic pressure testing limits in the 2021 edition provide equivalent safety to hydrostatic pressure testing limits in the 2007 edition.
7.1.1.2	Basis for Pneumatic Pressure Testing Limits	The 2007 and 2021 editions of Section I of the ASME BPVC do not include pneumatic pressure testing requirements.	An equivalent safety evaluation of pneumatic pressure testing requirements in the 2007 and 2021 editions is not possible.
7.2	Alternative Pressure Testing	The 2007 and 2021 editions of Section I of the ASME BPVC do not include alternative pressure testing requirements.	An equivalent safety evaluation of alternative pressure testing requirements in the 2007 and 2021 editions is not possible.
7.3.1	Proof Testing	Paragraph PG-18 in the 2007 and 2021 editions of Section I of the ASME BPVC states that where no rules are given for calculating the strength of a boiler or any part thereof, the Manufacturer may	The proof testing requirements in the

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section I of the ASME BPVC	Equivalent Safety Determination
		establish MAWP by testing a full-size sample in accordance with one of the following three test methods. • Strain Measurement Test • Displacement Measurement Test • Burst Test Corresponding proof test equations in the 2007 and 2021 editions of Section I of the ASME BPVC for computing MAWP using test data are the same.	2021 edition provide equivalent safety to the proof testing requirements in the 2007 edition
8.1.1	Overpressure Protection by Pressure Relief Device	Overpressure protection rules specified in Paragraph PG-67.4.2 in the 2007 and 2021 editions of Section I of the ASME BPVC limit the pressure of an operating boiler, except for the steam piping between the boiler and the prime mover, to 1.20 MAWP or less. This overpressure protection limit ensures that the primary membrane stress, P_m, does not exceed $0.80S_y$ (i.e., $1.20/1.50$). The rules for overpressure protection specified in the 2007 and 2021 editions of Section I of the ASME BPVC are the same. Therefore, the rules for overpressure protection specified in the 2021 edition of Section I of the ASME BPVC provide an equivalent level of safety compared to the rules for overpressure protection specified in the 2007 edition of Section I of the ASME BPVC.	The overpressure protection requirements by pressure relief device in the 2021 edition provide equivalent safety to the overpressure protection requirements by pressure relief device in the 2007 edition
8.1.2	Overpressure Protection by System Design	Section I of the ASME BPVC does not provide rules for overpressure protection by system design.	An equivalent safety evaluation of overpressure protection by system design in the 2007 and 2021 editions is not possible.

Table 9.2 Evaluation of equivalent safety for rules and requirements specified in the 2021 edition of Section VIII, Division 1 compared to correspond rules and requirements specified in the 2007 edition of Section VIII, Division 1 of the ASME BPVC

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
4.1.1.2	Excessive Elastic Deformation and Elastic Instability	Excessive elastic deformation (deflection) and elastic instability (buckling) cannot be controlled by imposing upper limits to the calculated stress alone because these behavioral phenomena are affected by component geometry and stiffness and material properties. Excessive elastic deformation can occur when a component with inadequate stiffness experiences unwanted flexibility or unacceptable deflections. Buckling is characterized by a sudden sideways failure of a component subjected to high compressive stress, where the compressive stress at the point of failure is less than the ultimate compressive stress that the material is capable of withstanding. The designer of a boiler or pressure vessel is responsible for applying engineering principles to understand and avoid in-service problems or failures caused by excessive elastic deformation and elastic instability. Paragraph UG-28 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC specifies rules for the design of shells and tubes under external pressure given in this Division are limited to cylindrical shells, with or without stiffening rings, tubes, and spherical shells. Three typical forms of cylindrical shells are shown in Figure UG-28. Charts used in determining minimum required thicknesses of these components are given in Section II, Part D, Mandatory Appendix 3, Subpart 3, Paragraph 3-100 in the 2007 and 2021editions of the ASME BPVC as discussed in Sect. 4.1.1.1 of this report.	Excessive elastic deformation and elastic instability requirements in the 2021 edition provide equivalent safety compared to excessive elastic deformation and elastic instability requirements in the 2007 edition.
4.1.2	Excessive Plastic Deformation	The plastic deformation mode of failure (ductile rupture) is controlled by imposing limits on calculated stress. Primary stress limits and primary plus secondary stress limits in the ASME BPVC are intended to prevent excessive plastic deformation leading to incremental collapse and to provide a nominal margin on the ductile burst pressure. The designer of a pressure vessel is responsible for ensuring that the specified stress limits are not exceeded under the operating conditions defined by the user. There are no rules specified in Section VIII, Division 1 of the ASME BPVC specifically for protection against plastic collapse. However, as discussed in Sect. 4.4.1 of this report, the maximum allowable membrane stress, P_m, for boilers and pressure vessels constructed in accordance with rules specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC is limited to two-thirds of the yield strength, $2/3S_y$, or less. Rules specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC also ensure that the primary membrane stress plus the primary bending stress, $P_m + P_b$, does not exceed S_y. Based on the principles of limit design theory discussed in Sect. 4.6 of this report, these rules provide a	Excessive plastic deformation requirements in the 2021 edition provide equivalent safety compared to excessive plastic deformation requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		minimum design margin against plastic collapse equal to or greater than 1.5. Additional discussion about protection against plastic collapse is presented in Sect. 4.8 of this report.	
4.1.3.2	Brittle Fracture	The ability of a metal to resist tearing or cracking is a measure of its fracture toughness. In fracture mechanics calculations, the value of the stress intensity factor, K_I, is based on the applied stress and dimensions of the flaw. To avoid brittle fracture, the calculated K_I must be less than the critical fracture toughness parameter, K_{Ic}. From an equivalency viewpoint, an increase in the maximum allowable design stress for a material with a critical flaw size requires an increase in fracture toughness to maintain the same margin against brittle fracture. In addition, increasing fracture toughness reduces the risk that critical flaw sizes below the NDE detection limits do not result in brittle fracture. Impact test requirements are specified in Paragraph UG-84 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. Minimum impact energy limits for carbon and low alloy steels listed in Table UCS-23 having a specified minimum tensile strength of less than 95 ksi are provided in Figure UG-84.1. These limits vary depending on the minimum specified yield strength and the material thickness. According to these limits: • The minimum impact energy, C_v, for all carbon and low alloy steels listed in Table UCS-23 with a maximum thickness of 1.375 in. and a minimum specified yield strength equal to 50 ksi or below is 15 ft-lb. • The minimum impact energy, C_v, for all carbon and low alloy steels listed in Table UCS-23 with a maximum thickness of 1.25 in. and a minimum specified yield strength between to 55 and 65 ksi is 20 ft-lb. According to rules specified in UG-20 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC, impact testing of carbon and low alloy steels is not required when the design temperature is no colder than -20ºC. Rules for impact tests for pressure vessels constructed of ferritic steels with tensile properties enhanced by heat treatment are specified in Part UHT of the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. These rules also apply to carbon and low alloy steels with a specified minimum tensile strength of 95 ksi or more. According to rules specified in Paragraph UHT-6 in the2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC, Charpy V-notch impact test specimens must exhibit a lateral expansion opposite the notch as specified in Figure UHT-6.1. These permissible lateral expansion values vary from 0.015 to 0.025 in. for materials that are between 1.25 and 3 in. thick.	Requirements in the 2021 edition for protection against brittle fracture provide equivalent safety compared to requirements in the 2007 edition for protection against brittle fracture.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		Toughness requirements for Cr–Mo steels with additional requirements for welding and heat treatment are specified in Paragraph 31-5 in Mandatory Appendix 31 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. These rules state that the minimum toughness requirements for base metal, weld metal, and heat affected zone, after exposure to the simulated postweld heat treatment Condition B, must be an impact energy equal to or greater than 40 ft-lb based on an average for three specimens with a 35 ft-lb minimum limit for one specimen in the set of three specimens for full size Charpy V-notch, transvers specimens tested at the MDMT. Part UNF in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC provide requirements for nonferrous materials. Rules specified in Paragraph UNF-65 state that nonferrous materials listed in Tables UNF-23.1 through UNF-23.5, together with deposited weld metal within the range of composition for material in that Table, do not undergo a marked drop in impact resistance at subzero temperature. Therefore, no additional requirements are provided for wrought aluminum alloys when they are used at temperatures down to -452°F (-269°C); for copper and copper alloys, nickel and nickel alloys, and cast aluminum alloys when they are used at temperatures down to -325°F (-198°C); and for titanium or zirconium and their alloys used at temperatures down to -75°F (-59°C).	
4.1.4.1	Stress Rupture and Creep Deformation	Boiler and pressure vessel materials that are in service above a certain temperature undergo continuing deformation (creep) at a rate that is strongly influenced by both stress and temperature. The temperature at which creep occurs varies with the alloy composition. To prevent excessive deformation and possible premature rupture it is necessary to limit the allowable stresses by additional criteria on creep-rate and stress-rupture. Criteria for establishing allowable stress values for Tables 1A and 1B are provided in Mandatory Appendix 1, Table 1-100 in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC. Allowable stress values in Tables 1A and 1B apply to materials permitted for pressure vessel construction. These criteria, which are discussed in Sect. 4.4.1 of this report, cover temperatures in the range where creep and stress rupture strength govern the selection of stresses. The criteria for establishing allowable stress values provided in Mandatory Appendix 1, Table 1-100 in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC are the same.	Stress rupture and creep deformation requirements in the 2021 edition provide equivalent safety compared to stress rupture and creep deformation requirements in the 2007 edition.
4.1.5.2	Plastic Instability – Incremental Collapse	Ratcheting is defined as a progressive incremental inelastic deformation or strain that can occur in a component subjected to variations of mechanical stress, thermal stress, or both. Ratcheting is produced by a sustained load acting over the full cross section of a component, in combination with a strain controlled cyclic load or temperature distribution that is alternately applied and removed. Ratcheting results in cyclic straining of the material, which can result in failure by fatigue and at	Plastic instability and incremental collapse requirements in the 2021 edition provide equivalent safety compared to plastic

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		the same time produces cyclic incremental deformation of a component, which may ultimately lead to collapse. Paragraph U-2*(a)* in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC states that the user or his designated agent must establish the design requirements for pressure vessels, taking into consideration factors associated with normal operation, such other conditions as startup and shutdown, and abnormal conditions which may become a governing design consideration. When cyclic service is a design consideration, the user or his designated agent must state if a fatigue analysis is required. Rules specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC do not: • require calculation of thermal stresses and do not provide allowable values for them • require the detailed calculation and classification of all stresses and the application of different stress limits to different classes of stress • consider the possibility of fatigue failure [6] Instead, rules in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC provide equations for minimum wall thickness based on the maximum stress theory discussed in Sect. 4.5.1 of this report. Consequently, no plastic instability and incremental collapse requirements associated with ratcheting are specified in either the 2007 or the 2021 edition of Section VIII, Division 1 of the ASME BPVC.	instability and incremental collapse requirements in the 2007 edition.
4.1.6.2	Fatigue	Fatigue is the weakening of a material caused by repeatedly applied loads. It is the progressive and localized material degradation that occurs when a component is subjected to cyclic loading. If the loads are above a certain threshold, microscopic cracks will begin to form at stress concentrations such as square holes or sharp corners. Eventually the crack will reach a critical size, propagate, and cause the component to fracture. Avoidance of discontinuities that increase local stresses will increase the fatigue life of a component subjected to cyclic loading. Paragraph U-2*(a)* in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC states that the user or his designated agent must establish the design requirements for pressure vessels, taking into consideration factors associated with normal operation, such other conditions as startup and shutdown, and abnormal conditions which may become a governing design consideration. Rules specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC do not: • require calculation of thermal stresses and do not provide allowable values for them	Fatigue requirements in the 2021 edition provide equivalent safety compared to fatigue requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		• require the detailed calculation and classification of all stresses and the application of different stress limits to different classes of stress • consider the possibility of fatigue failure [6] Instead, rules in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC provide equations for minimum wall thickness based on the maximum stress theory discussed in Sect. 4.5.1 of this report. Consequently, no rules for fatigue are specified in either the 2007 or the 2021 edition of Section VIII, Division 1 of the ASME BPVC.	
4.1.7.2	Stress Corrosion and Corrosion Fatigue	Two common types of corrosion that can adversely affect the integrity of a boiler or pressure vessel include stress corrosion cracking and corrosion fatigue. Stress corrosion cracking (SCC) is the growth of crack formation in a corrosive environment and is highly chemically specific in that certain alloys are likely to undergo SCC only when exposed to a small number of chemical environments. Corrosion fatigue is the mechanical degradation of a material under the joint action of corrosion and cyclic loading. Since corrosion-fatigue cracks initiate at a metal's surface, surface treatments like plating, cladding, nitriding, and shot peening can improve the materials' resistance to corrosion fatigue. However, corrosion fatigue only occurs when the metal is under tensile stress. Rules for corrosion are specified in Paragraph UG-25 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. These rules state that the user or his designated agent must specify corrosion allowances other than those required by the rules of this Division. In addition, vessels or parts of vessels subject to thinning by corrosion, erosion, or mechanical abrasion shall have provision made for the desired life of the vessel by a suitable increase in the thickness of the material over that determined by the design formulas, or by using some other suitable method of protection.	Stress corrosion cracking and corrosion fatigue requirements in the 2021 edition provide equivalent safety compared to stress corrosion cracking and corrosion fatigue requirements in the 2007 edition.
4.2.2	Design Basis	Mandatory requirements specified in Paragraph U-2 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC state that the user or his designated agent (See Nonmandatory Appendix NN – Guidance to the Responsibilities of the User and Designated Agent) shall establish the design requirements for pressure vessels, taking into consideration factors associated with normal operation, such other conditions as startup and shutdown, and abnormal conditions which may become a governing design consideration (See UG-22 – Loadings). Paragraph U-2*(a)* further states that such consideration shall include but shall not be limited to the following: *(1)* the need for corrosion allowances. *(2)* the definition of lethal services. For example, see UW-2(a).	Design basis requirements in the 2021 edition provide equivalent or greater safety compared to design basis requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		(3) the need for postweld heat treatment beyond the requirements of this Division and dependent on service conditions. *(4)* for pressure vessels in which steam is generated, or water is heated [see U-1*(g)* and U-1*(h)*], the need for piping, valves, instruments, and fittings to perform the functions covered by Section I, PG-59 through PG-61. *(5)* the degree of nondestructive examination(s) and the selection of applicable acceptance standards when such examinations are beyond the requirements of this Division. (This consideration is not required in the Paragraph U-2*(a)* in the 2007 edition.) Sample UDS forms and guidance on their preparation are found in Nonmandatory Appendix KK – Guide for Preparing User's Design Requirements. This sample form might not be applicable to all pressure vessels that may be constructed in accordance with this Division. The user is cautioned that input from the Manufacturer may be necessary for completion of this form. Guidance for the responsibilities of the user and designated agent is provided in Nonmandatory Appendix NN – Guidance to the Responsibilities of the User and Designated Agent in the 2021 edition of Section VIII, Division 1 of the ASME BPVC. Nonmandatory Appendix NN provides a directory for locating the specific Code-assigned responsibilities and other considerations assigned to the user or his designated agent as applicable to the pressure vessel under consideration. These responsibilities and considerations are grouped into 11 categories as defined in NN-6*(a)*, and the Code paragraphs relevant to each category are detailed in Tables NN-6-1 through NN-6-11.	
4.4.1, 4.4.3, and 4.4.6.1	Allowable Stress Values	Criteria for establishing allowable stress values for Tables 1A and 1B are provided in Mandatory Appendix 1, Table 1-100 in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC. Tables 1A and 1B provides allowable stresses for materials permitted for Section VIII, Division 1 construction. In general, yield to tensile strength ratios for steels increase with increasing tensile strength. Allowable stress values specified in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC are compared in Tables 4.4 and 4.5 of this report. It is also important to note that the maximum allowable stress specified in both the 2007 and 2021 editions of Section II, Part D may equal, but can never exceed, two-thirds of the specified minimum yield strength at room temperature, 2/3 S_y. Alternative rules for maximum allowable stress values in tension for pressure vessels constructed using materials having higher allowable stresses at low temperature are tabulated in Part ULT of the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. Part ULT also includes rules that cover design, fabrication, inspection, testing, marking, reports, and overpressure	Allowable stress rules in the 2021 edition provide equivalent safety to allowable stress rules in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		protection. Paragraph ULT-5 – General in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC states that material covered by Part ULT subject to stress due to pressure shall conform to one of the specifications given in Section II and shall be limited to those listed in Table ULT-23. The title of Table ULT-23 is: V001 Maximum Allowable Stress Values in Tension for 5%, 7%, 8%, and 9% Nickel Steels; Types 304 and 316 Stainless Steels; and 5083 0 Aluminum Alloy at Cryogenic Temperatures for Welded and Nonwelded Construction. Maximum allowable stress values specified in Table ULT-23 are provided for temperatures between -320°F and 150°F (100°F in the 2007 edition). Criteria for establishing allowable stress values in Table 3 are provided in Mandatory Appendix 2, Table 2-120*(a)* in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC. Table 3 provides allowable stress values for bolting materials for use in Section VIII, Division 1 and Section VIII, Division 2 (using Part 4.16 of Section VIII, Division 2) construction. Allowable stress values at any temperature are provided in Table 3 for materials whose strength has not been enhanced by heat treatment or by strain hardening and materials whose strength has been enhanced by heat treatment or by strain hardening. The maximum allowable design stress values published in Tables 1A and 1B the 2007 and 2021 editions of Section II, Part D of the ASME BPVC that are intended for use in Section VIII, Division 1 are based on the following stress limits as discussed in Sect. 4.6 of this report. $P_m \leq S_y$ Stress limit {4.5} $P_m + P_b \leq 1.5S_y$ Stress limit {4.6} Adequate safety against plastic collapse for pressure vessels constructed in accordance with rules specified in the 2007 and 2021 editions of Section VIII, Divisions 1 and 2 is achieved by limiting design stresses to 2/3 of these stress limits as stated in Equations {4.7} and {4.8}. $P_m \leq 0.67S_y$ Design stress limit {4.7} $P_m + P_b \leq 1.0S_y$ Design stress limit {4.8} In comparison, adequate safety against plastic collapse for boilers constructed in accordance with rules specified in the 2007 and 2021 editions of Section I is achieved by limiting the design membrane stress, P_m, to $2/3S_y$ to be consistent with the maximum stress theory. For boiler components in which bending produces the maximum stress, the design bending stress, P_b, is similarly limited to $2/3S_y$.	

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
4.5.1	Strength Theory	Equations specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC for determining wall thickness are, by implication, consistent with the maximum stress theory discussed in Sect. 4.5.1 of this report.	Design membrane stress limits in the 2021 edition provide equivalent safety to design membrane stress limits in the 2007 edition.
4.7	Stress Range for Repetitively Applied Loads	Shakedown of a component occurs if, after a few cycles of load application, ratcheting ceases. The subsequent structural response is elastic or elastic-plastic, and progressive incremental inelastic deformation is absent. Elastic shakedown is the case in which the subsequent response is elastic. The ASME BPVC limits localized discontinuity stresses to 3.0 times the maximum allowable stress value in tension or 2.0 times the minimum specified tensile yield stress, S_y, of the material provided the allowable stress is not governed by time-dependent properties of the material and the room temperature ratio of the specified minimum yield strength, S_y, to specified minimum tensile strength, S_u, for the material does not exceed 0.7. This requirement ensures the material has strain-hardening properties sufficient to prevent material failure if the primary stress exceeds the yield strength of the material through the entire thickness. Further discussion about stress range for repetitively applied loads are presented in Sect. 4.7 of this report. Text in Paragraph UG-23*(c)* in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC state that it is recognized that high localized discontinuity stresses may exist in vessels designed and fabricated in accordance with these rules. Insofar as practical, design rules for details have been written to limit such stresses to a safe level consistent with experience. Therefore, Section VIII, Division 1 of the ASME BPVC does not include rules for the 'shakedown' phenomenon.	Rules for stress range for repetitively applied loads in the 2021 edition provide equivalent safety to rules for stress range for repetitively applied loads in the 2007 edition.
4.8.1	Plastic Collapse Stress Limits	Plastic collapse is the load at which overall structural instability occurs. The collapse load is the maximum load limit for a component made of elastic perfectly plastic material. Deformations of these components increase without bound at the collapse load. Adequate safety against plastic collapse for pressure vessels constructed in accordance with rules specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC is achieved by limiting design membrane stress, P_m, to two-thirds of the yield strength, $2/3S_y$, and by limiting primary membrane stress plus primary bending stress, $P_m + P_b \leq 1.0S_y$, to the yield strength, S_y.	Allowable stress rules in the 2021 edition provide equivalent safety to allowable stress rules in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		This upper limit proves a minimum design margin of 1.5 against plastic collapse as discussed in Sect. 4.6 of this report. Rules specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC do not require a detailed stress analysis to evaluate protection against plastic collapse but merely set the wall thickness necessary to keep the basic hoop stress below the tabulated allowable stress. As discussed in Sect. 4.4.1 of this report, the maximum allowable stress for boilers constructed in accordance with rules specified in Section VIII, Division 1 of the ASME BPVC is limited to two-thirds of the yield strength, $2/3S_y$, or less. Based on the principles of limit design theory discussed in Sect. 4.6 of this report, the minimum design margin against plastic collapse is at least 1.5.	
4.9.2	Design-by-Rule	The design approach used in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC is referred to as design-by-rule. This design-by-rule approach is not based on detailed stress analysis. Instead, design-by-rule generally involves calculation of average membrane stress across the thickness of the walls of the pressure vessel or component. As discussed in Sect. 4.5.1 of this report, rules in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC are based on the maximum stress theory. Rules for openings and reinforcements in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC are based on the area replacement concept in which the metal cut out by an opening must be replaced by reinforcement within a prescribed zone around the opening. Supplementary design formulas are specified in Mandatory Appendix 1 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC for certain types of openings.	The design-by-rule approach in the 2021 editions provides equivalent safety to the design-by-rule approach in the 2007 editions.
4.10	Design-by-Analysis	The 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC do not include design-by-analysis requirements.	An equivalent safety evaluation of design-by-analysis requirements in the 2007 and 2021 editions is not possible.
5.1.2	Forming Deviations	Rules for fabrication of pressure vessels are specified in Paragraphs UG-75 through UG-85 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. These rules cover the topics described in Sect. 5.1.2 of this report. Paragraph UG-79 – Forming Pressure Parts in the 2021 edition of Section VIII, Division 1 specifies additional rules that are not specified in the 2007 edition of Section VIII, Division 1 of the ASME BPVC. Paragraph UG-79*(a)* states:	Forming deviations in the 2021 edition provide equivalent or greater safety to forming deviations in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		Limits are provided on cold working of all carbon and low alloy steels, nonferrous alloys, high alloy steels, and ferritic steels with tensile properties enhanced by heat treatment [see UCS 79(d), UNF-79(a), UHA-44(a), and UHT-79(a)]. Forming strains or extreme fiber elongation shall be determined by the equations in Table UG-79-1. Table UG-79-1 – Equations for Calculating Forming Strains specifies forming strain equations for cylinders formed from plate, for double curvature (e.g., heads), and tube and pipe bends. When the calculated forming strains exceed the maximum prescribed allowable strains specified in Paragraphs UCS-79(*d*), UHA-44(*a*), UNF-79(*a*), and UHT-79(*a*), as applicable, and the design temperatures exceed specified limits, postfabrication heat treatment is required.	
5.2.1.2	Formed Head Tolerances	The same shape deviation requirements for formed heads are specified in Paragraph UG-81 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. These requirements apply to inner surfaces of a torispherical, toriconical, hemispherical, and ellipsoidal heads.	Formed head tolerances in the 2021 edition provide equivalent safety to formed head tolerances in the 2007 edition.
5.2.2	Alignment Tolerances	Paragraph UW-33 – Alignment Tolerance in the 2007 and 2021editions of Section VIII, Division 1 of the ASME BPVC specify rules for alignment tolerances for edges to be butt welded. The maximum allowable offsets in welded joints are specified in Table UW-33. Alignment tolerance values provided in Table UW-33 are the same in 2007 and 2021 editions.	Alignment tolerances in the 2021 edition provide equivalent safety to alignment tolerances in the 2007 edition.
5.3.1	Base Metal Groupings	Base metals permitted for boiler and pressure vessel construction are grouped by material and assigned P-Numbers. For example, carbon manganese or low carbon steel base metals are assigned to P-No. 1. Table QW/QB-422 in the 2007 and 2021 editions of Section IX in the ASME BPVC provides a cross reference between P-Number and ferrous and nonferrous materials. P-Numbers are assigned to base metals for the purpose of reducing the number of welding and brazing procedure qualifications required. P-Numbers are alphanumeric designations: accordingly, each P-Number must be considered a separate P-Number (e.g., base metals assigned P-No. 5A are considered a separate P-Number from those assigned P-No. 5B or P-No. 5C).	P-Numbers in the 2021 edition provide equivalent safety to P-Numbers in the 2007 edition.
5.3.2	Welding and Brazing Methods	Rules for welding and brazing are specified in Part QW and Part QB, respectively, in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for plastic fusing are only specified in Part QF in the 2021 edition of Section IX of the ASME BPVC.	Welding and brazing methods in the 2021 edition provide equivalent safety to

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		All of the welding and brazing methods permitted in the 2007 edition are also permitted in the 2021 edition. However, Diffusion Welding (DFW), Low-Power Density Laser Beam Welding (LLBW), and Friction Stir Welding (FSW) are also permitted in the 2021 edition.	welding and brazing methods in the 2007 edition. Fusing method rules are not specified in the 2007 edition.
5.3.3	Rules in Section IX for Procedure Specification	A Procedure Specification addresses the conditions (including ranges, if any) under which the material joining process must be performed. These conditions are referred to as “variables.” When a Procedure Specification is prepared by the organization, it must address, as a minimum, the specific essential and nonessential variables that are applicable to the material joining process to be used in production. When toughness qualification of the material joining procedure is required, the applicable supplementary essential variables must also be addressed in the Procedure Specification. Rules for welding procedure qualification are specified in Part QW, Article II in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for brazing procedure qualification are specified in Part QB, Article XII in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for plastic fusing procedure qualification are only specified in Part QF, Article XXII in the 2021 edition of Section IX of the ASME BPVC.	Procedure specification rules in the 2021edition provide equivalent safety to procedure specification rules in the 2007 edition. Procedure specification rules for fusing are not specified in the 2007 edition.
5.3.4	Rules in Section IX for Procedure Qualification Record (PQR)	The Procedure Qualification Record (PQR) documents what occurred during the production of a procedure qualification test coupon and the results of testing that coupon. As a minimum, the record must document the essential variables for each process used to produce the test coupon, the ranges of variables qualified, and the results of the required testing and nondestructive examinations. The organization must certify a PQR by a signature or other means as described in the organization’s Quality Control System and must make the PQR accessible to the Authorized Inspector. Rules that govern PQR are specified in Paragraph QW-200.2 for welding and QB-200.2 for brazing in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules that govern PQR for plastic fusing are specified in Paragraph QF-201.5 for in the 2021 edition of Section IX of the ASME BPVC.	Procedure qualification record rules in the 2021 edition provide equivalent safety to procedure qualification record rules in the 2007 edition.
5.3.5	Rules in Section IX for Performance Qualification	The purpose of qualifying the person who will use a joining process is to demonstrate that person’s ability to produce a sound joint when using a Procedure Specification.	Performance qualification rules in the 2021 edition provide equivalent

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		Rules for welding performance qualification are specified in Part QW, Article III in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for brazing performance qualification are specified in Part QB, Article XIII in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for plastic fusing performance qualification are only specified in Part QF, Article XXIII in the 2021 edition of Section IX of the ASME BPVC.	safety to performance qualification rules in the 2007 edition. Performance qualification rules for fusing are not specified in the 2007 edition.
5.3.6	Rules in Section IX for Performance Qualification Record	The performance qualification record documents what occurred during the production of a test coupon by a person using one or more joining processes following an organization's PS. As a minimum, the record shall document: *(a)* the essential variables for each process used to produce the test coupon *(b)* the ranges of variables qualified as required by the applicable part (see QW-301.4, QB-301.4, and QF-301.4) *(c)* the results of the required testing and nondestructive examinations *(d)* the identification of the procedure specification(s) followed during the test Rules for Welder/Welding Operator Performance Qualification (WPQ) are specified in Paragraph QW-301.4 in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for Brazer or Brazing Operator Performance Qualification (BPQ) are specified in Paragraph QB-301.4 in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for Fusing Operator Performance Qualification Record (FPQ) are specified in Paragraph QF-301.4 in the 2021 edition of Section IX of the ASME BPVC.	Performance qualification record rules in the 2021 edition provide equivalent safety to performance qualification record rules in the 2007 edition. Performance qualification record rules for fusing are not specified in the 2007 edition.
5.3.7	Rules in Section IX Welding, Brazing, and Fusing Data	Welding, brazing, and fusing data articles include the variables grouped into categories such as joints, base materials and filler materials, positions, preheat and postweld heat treatment, gas, electrical characteristics, and technique. These variables are referenced from other articles as they apply to each process. Welding data include essential, supplementary essential, or nonessential variables. Brazing data include essential and nonessential variables. Fusing data include the fusing variables grouped as joints, pipe material, position, thermal conditions, equipment, and technique. Rules for welding data are specified in Part QW, Article IV in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for brazing data are specified in Part QB, Article XIV in	Welding and brazing, data rules in the 2021 edition provide equivalent safety to welding and brazing, data rules in the 2007 edition. Fusing data rules are not specified in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for fusing data are only specified in Part QF, Article XXIV in the 2021 edition of Section IX of the ASME BPVC.	
5.4.1.2	Preheating Requirements	The WPS for the material being welded specifies the minimum preheating requirements in accordance with the weld procedure qualification requirements of Section IX that apply to pressure vessels constructed in accordance with rules specified in Section VIII, Division 1 of the ASME BPVC. Mandatory rules for preheating are not given in Section VIII, Division 1 of the ASME BPVC except as required in the footnotes that provide for exemptions to postweld heat treatment in Tables UCS-56 and UHA-32 in the 2007 edition and Tables UCS-56-1 through UCS 56-11 and Tables UHA-32-1 through UHA-32-7 in the 2021 edition.	Preheating rules in the 2021 edition provide equivalent safety to preheating rules in the 2007 edition.
5.4.2.2	Postweld Heat Treatment Requirements	Rules for postweld heat treatment are specified in Paragraph UW-40 – Repair of Defects in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. According to rules specified in Paragraph UW-40*(a)*, minimum postweld heat treatment normal holding temperatures are specified in Table UCS-56 in the 2007 edition for P-Numbers 1, 3, 4, 5A, 5B, 5C, 9A, 9B, 10A, 10B, and 10F materials and Tables UCS-56-1 through UCS-56-11 in the 2021 edition for P-Numbers 1, 3, 4, 5A, 5B, 5C, 9A, 9B, 10A, 10C, and 15E materials. Requirements for postweld heat treatment provided in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC cover materials from different groups of P-Numbers as described in Sect. 5.3.1 of this report.	Postweld heat treatment rules in the 2021 edition provide equivalent safety to postweld heat treatment rules in the 2007 edition.
5.5	Cold Stretching	Cold stretching is a pressure vessel construction method that was incorporated into the ASME BPVC through approval of Code Case 2596 on January 29, 2008. This method of construction involves fabrication of a pressure vessel from ductile material, and then subjecting the pressure vessel to a hydrostatic pressure that causes the material to plastically deform (i.e., stretch). Mandatory Appendix 44 in the 2021 edition of Section VIII, Division 1 of the ASME BPVC specifies requirements for design, construct, and stamping of cold-stretched austenitic stainless steel pressure vessels in addition to those provided in Section VIII, Division 1. However, rules in Paragraph 44-4 restrict design and fabrication of cold-stretched pressure vessels to specific austenitic stainless steels.	An equivalent safety evaluation of cold stretching requirements in the 2007 and 2021 editions is not possible.
5.6.2	Quality Control System	Quality control system requirements are provided in Paragraph UG-117*(e)* – Quality Control System in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. This paragraph in the 2021 edition states that any Manufacturer holding or applying for a Certificate of Authorization shall demonstrate a quality control program that meets the requirements of ASME	Quality control system requirements in the 2021 edition provide equivalent safety to

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		CA-1 and establishes that all Code requirements, including material, design, fabrication, examination (by the Manufacturer), inspection of vessel and vessel parts (by the Authorized Inspector or Certified Individual, as applicable), pressure testing, and certification, will be met. The Quality Control System shall be in accordance with the requirements of Mandatory Appendix 10 – Quality Control System in the 2021 edition of Section VIII, Division 1 of the ASME BPVC. Rules specified in Paragraph UG-91*(a)(2)* state that all Inspectors shall have been qualified in accordance with ASME QAI-1, *Qualifications for Authorized Inspection*. Publication ASME CA-1 [2] specifies requirements for accreditation and certification of organizations supplying products or services that are intended to conform to the requirements of ASME standards listed in Table 1 – ASME Certification Programs. Table 1 in ASME CA-1 assigns the ASME Certification Designator "U – Pressure Vessel, Division 1" to Section VIII, Division 1 of the ASME BPVC. Publication ASME CA-1 was initially issued in 2013.	quality control system requirements in the 2007 edition.
6.2.2	General NDE Requirements	Rules for volumetric and surface examinations of joints in pressure vessels that are fabricated by welding and require examination are specified in Paragraphs UW-11 – Radiographic and Ultrasonic Examination and UG-103 – Nondestructive Testing, respectively, in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. Rules in Paragraph UW-11 – Radiographic and Ultrasonic Examination in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC require radiographic and ultrasonic examinations of welded joints as specified in the following paragraphs. • UW-11*(a)* – full radiography (2007 and 2021 editions) • UW-11*(b)* – spot radiography (2007 and 2021 editions) • UW-11*(c)* – no radiography (2007 and 2021 editions) • UW-11*(d)* – electrogas welds in ferritic materials (2007 and 2021 editions) • UW-11*(e)* – welds made by the electron beam or laser beam process (2021 edition) • UW-11*(f)* – welds made by the inertia and continuous drive friction welding process (2021 edition) The scope of radiographic and ultrasonic examination requirements in Paragraph UW-11 expanded in the 2021 edition (see UW-11*(e)* and UW-11*(f)* above). Rules specified in Paragraph UG-103 state that where magnetic particle examination is prescribed in Section VIII, Division 1 it must be performed in accordance with Mandatory Appendix 6 – Methods for Magnetic Particle Examination (MT), and where liquid penetrant examination is	General NDE requirements in the 2021 edition provide equivalent safety to general NDE requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		prescribed in this Division it must be performed in accordance with Mandatory Appendix 8 – Methods for Liquid Penetrant Examination (PT). Rules specified in Paragraph UW-54 – Qualification of Nondestructive Examination Personnel in the 2021 edition of Section VIII, Division 1 of the ASME BPVC state that personnel performing nondestructive examinations in accordance with UW-51 – Radiographic Examination of Welded Joints, UW-52 – Spot Examination of Welded Joints, or UW-53 – Ultrasonic Examination of Welded Joints shall be qualified and certified in accordance with the requirements of Section V, Article 1 – General Requirements, T-120*(e)*, T-120*(f)*, T-120*(g)*, T-120*(i)*, T-120*(j)*, or T-120*(k)*, as applicable. As discussed in Sect. 6.3.1 of this report, rules specified in Section V, Article 1 – General Requirements, T-120*(e)* in the 2021 edition of Section VIII, Division 1 of the ASME BPVC reference the 2016 edition of SNT-TC-1A and CP-189. Corresponding rules specified in Paragraph UW-51 – Radiographic Examination of Welded Joints, Paragraph UW-52 – Spot Examination of Welded Joints, and Mandatory Appendix 12 – Ultrasonic Examination of Welds (UT), Paragraph 12-2 – Certification of Competence of Nondestructive Examiner in the 2007 edition of Section VIII, Division 1 of the ASME BPVC reference the 2001 edition of SNT-TC-1A and CP-189. Qualifications for nondestructive examination personnel to perform magnetic particle examinations and liquid penetrant examinations are provided in Mandatory Appendix 6 – Methods for Magnetic Particle Examination (MT) and Mandatory Appendix 8 – Methods for Liquid Penetrant Examination (PT), respectively, in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. However, neither of these Mandatory Appendices in the 2007 and 2021 editions required certification of nondestructive examination personnel to perform magnetic particle examinations and liquid penetrant examinations in accordance with Section V, Article 1 – General Requirements, T-120*(e)* as discussed in Sect. 6.3.1 of this report. Rules for visual examination (VT) of pressure vessels constructed of ferrous and nonferrous materials are not specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. However, Paragraph UIG-96 – Qualification of Visual Examination Personnel in the 2021 edition of Section VIII, Division 1 of the ASME BPVC provides qualification requirements for personnel who perform visual examinations of pressure vessels constructed of impregnated graphite. These rules state that the methods used to qualify and certify personnel must be in accordance with a program established by the employer of the personnel being certified, which are based on the minimum requirements provided in UIG-96*(a)* through *(e).* Corresponding requirements for qualification of visual examination personnel are not provided in the 2007 edition of Section VIII, Division 1 of the ASME BPVC.	

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		Rules specified in Mandatory Appendix 42 – Diffusion Welding of Microchannel Heat Exchangers in the 2021 edition of Section VIII, Division 1 require that visual examinations shall be performed in accordance with Section V, Article 9. Mandatory Appendix 42 is not included in the 2007 edition of Section VIII, Division 1 of the ASME BPVC.	
6.2.2.1	Radiographic Examination Requirements	Rules for radiographic examination of welded joints are specified in Paragraph UW-51 – Radiographic Examination of Welded Joints in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. These rules state that all welds that require radiographic examination must be examined in accordance with rules specified in Article 2 – Radiographic Examination, Section V of the ASME BPVC, except as specified in Paragraphs UW-51*(a)(1)* through *(a)(4)*. Paragraphs UW-51*(b)(1)* through *(b)(4)* define the conditions under which indications shown on the radiographs of welds and characterized as imperfections are unacceptable and must be repaired and the repair radiographed. Acceptance standards for full radiographic examinations are compared in Sect. 6.2.4.2 of this report. Rules for spot radiographic examination of butt-welded joints are specified in Paragraph UW-52 – Spot Examination of Welded Joints in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. Paragraph UW-52*(c)* states that the minimum length of a spot radiograph is 6 in. (150 mm). Requirements for the minimum extent of spot radiographic examinations are provided in Paragraph UW-52*(b)*. Acceptance standards for spot radiographic examinations are compared in Sect. 6.2.4.2 of this report.	Radiographic examination requirements in the 2021 edition provide equivalent or greater safety to radiographic examination in the 2007 edition.
6.2.2.2	Ultrasonic Examination Requirements	Rules for ultrasonic examination of welded joints are specific in Paragraph UW-53 – Ultrasonic Examination of Welded Joints in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. According to these rules, ultrasonic examination of welded joints when required or permitted by other paragraphs of this Division must be performed and evaluated to the acceptance standards in accordance with Mandatory Appendix 12 – Ultrasonic Examination of Welds (UT) in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC, as applicable. Paragraph 12 1*(b)* in Mandatory Appendix 12 states that Section V, Article 4 shall be applied for detail requirements in methods and procedures, unless otherwise specified in this Appendix. Rules specified in Paragraph UW-51*(a)(4)* in the 2021 edition of Section VIII, Division 1 of the ASME BPVC state: *As an alternative to the radiographic examination requirements above, all welds in which the thinner of the members joined is 1/4 in. (6 mm) thick and greater may be examined using the ultrasonic (UT) method specified by UW-53(b).*	Ultrasonic examination requirements in the 2021 edition provide equivalent or greater safety to ultrasonic examination in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		Paragraph UW-53*(b)* states that ultrasonic examination of welds per UW-51*(a)(4)* shall be performed and evaluated in accordance with the requirements of Section VIII, Division 2, Paragraph 7.5.5. Acceptance standards for ultrasonic examinations and flaw evaluation specified in Section VIII, Division 2, Paragraph 7.5.5 are discussed in Sect. 6.2.4.2 of this report.	
6.2.2.3	Magnetic Particle Examination Requirements	Rules for magnetic particle examination are specified in Mandatory Appendix 6 – Methods for Magnetic Particle Examination (MT) in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. These rules describe methods which must be employed whenever magnetic particle examination is specified in this Division. Magnetic particle examination must be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of T-150 of Section V of the ASME BPVC. Acceptance standards for magnetic particle examinations are compared in Sect. 6.2.4.2 of this report of this report.	Magnetic particle examination requirements in the 2021 edition provide equivalent safety to magnetic particle examination in the 2007 edition.
6.2.2.4	Liquid Penetrant Examination Requirements	Rules for liquid penetrant examination are specified in Mandatory Appendix 8 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. These rules describe methods which must be employed whenever liquid penetrant examination is specified in this Division. Liquid penetrant examination must be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of T-150 of Section V of the ASME BPVC. Acceptance standards for liquid penetrant examinations are compared in Sect. 6.2.4.2 of this report of this report.	Liquid penetrant examination requirements in the 2021 edition provide equivalent safety to liquid penetrant examination requirements in the 2007 edition.
6.2.2.5	Visual Examination Requirements	Rules for visual examination of pressure vessels constructed of ferrous and nonferrous materials are not specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. However, rules for visual examination of pressure vessels constructed of impregnated graphite are specified in Paragraph UIG-95 – Visual Examination in the 2021 edition of Section VIII, Division 1 of the ASME BPVC. Corresponding rules for visual examination of impregnated graphite pressure vessels are not specified in the 2007 edition of Section VIII, Division 1 of the ASME BPVC. Rules specified in Mandatory Appendix 42 – Diffusion Welding of Microchannel Heat Exchangers in the 2021 edition of Section VIII, Division 1 require that visual examinations shall be performed in accordance with Section V, Article 9. Mandatory Appendix 42 is not included in the 2007 edition of Section VIII, Division 1 of the ASME BPVC.	Visual examination requirements in the 2021 edition provide equivalent or greater safety to visual examination requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
6.2.4.2	NDE Acceptance Standards	Acceptance standards provided in Section VIII, Division 1 for radiographic, ultrasonic, magnetic particle, and liquid penetrant examinations are comparable. However, compared to the 2007 edition, acceptance standards for radiographic examinations in the 2021 edition of Section VIII, Division 1 are expanded for both linear and rounded indications. In addition, ultrasonic examination criteria are added to the 2021 edition of Section VIII, Division 1 as an alternative to radiographic examinations for welded joints.	NDE acceptance standards in the 2021 edition provide equivalent safety to NDE acceptance standard in the 2007 edition.
6.2.5	Summary of Qualification and Certification Requirements for NDE Personnel	As discussed in Sect. 6.1 of this report, the Manufacturer is responsible for training, qualifying, and certifying of NDE personnel that perform NDE methods and evaluate NDE results. Requirements for qualification and certification for NDE personnel that are provided in Section I; Section VIII, Division 1; and Section VIII, Division 2 of the ASME BPVC are discussed in Sects. 6.2.1, 6.2.2, and 6.2.3 of this report, respectively. Table 6.6 is a crosswalk that maps paragraphs in Section I; Section VIII, Division 1; and Section VIII, Division 2 that provide qualification and certification requirements for NDE personnel to reference sections in this report where these qualification and certification requirements are examined and explained.	Certification requirement for NDE personnel in the 2021 edition provide equivalent safety to certification requirement for NDE personnel in the 2007 edition.
6.3.1	General NDE Requirements in Section V	Article 1 – General Requirements in the 2007 and 2021 editions of Section V of the ASME BPVC provide general requirements and methods for NDE which are Code requirements to the extent they are specifically referenced and required by a Construction Code or referencing documents. These NDE methods are used to detect surface and internal imperfections in materials, welds, fabricated parts, and components. Rules for certification of nondestructive examination personnel are specified in Paragraphs T-120*(e)* and *(f)* in the 2021 edition of Section V of the ASME BPVC. These rules state: *(e) For those documents that directly reference this Article for the qualification of NDE personnel, the qualification shall be in accordance with their employer's written practice which shall be in accordance with one of the following documents:* *(1) SNT-TC-1A (2016 Edition), Personnel Qualification and Certification in Nondestructive Testing, as amended by Mandatory Appendix III; or* *(2) ANSI/ASNT CP-189 (2016 Edition), ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel, as amended by Mandatory Appendix IV* *(f) National or international central certification programs, such as the ASNT Central Certification Program (ACCP) or ISO 9712:2012-based programs, may be alternatively*	General NDE requirements in the 2021 edition provide equivalent safety to general NDE requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		used to fulfill the training, experience, and examination requirements of the documents listed in (e) as specified in the employer's written practice. By comparison, Paragraph T-120*(e)* in the 2007 edition of Section V of the ASME BPVC specified the 2001 editions of SNT-TC-1A and ANSI/ASNT CP-189, and Paragraph T-120*(f)* in the 2007 edition of Section V of the ASME BPVC added ISO 9712:2012-based programs as an example of a National or international central certification program. Addition rules for certification of NDE personnel are provided in Paragraphs T-120*(g)* and *(h)* in the 2021 edition of Section V of the ASME BPVC. These rules state: *(g) In addition to the requirements described in (e) or (f) above, if the techniques of computed radiography (CR), digital radiography (DR), phased-array ultrasonic (PAUT), ultrasonic time-of-flight diffraction (TOFD), or ultrasonic full matrix capture (FMC) are to be used, the training, experience, and examination requirements found in Article 1, Mandatory Appendix II shall also be included in the employer's written practice for each technique as applicable.* *(h) Alternatively, performance-based qualification programs, in accordance with ASME ANDE-1-2015, ASME Nondestructive Examination and Quality Control Central Qualification and Certification Program, may be used for training, experience, examination, and certification activities as specified in the written practice.* The alternative rules for performance-based qualification programs permitted in Paragraphs T-120*(h)* in the 2021 edition of Section V are not included in the 2007 edition of Section V of the ASME BPVC.	
6.3.2	Radiographic Examination Requirements in Section V	Article 2 – Radiographic Examination in the 2007 and 2021 editions of Section V of the ASME BPVC provides requirements for radiographic examination of materials including castings and welds. The extent of radiographic examinations is as specified by the referencing Construction Code. Product-specific, technique-specific, and application-specific requirements are also provided in mandatory appendices provided in Section V, Article 2. Paragraph III-210 in Mandatory Appendix III in the 2007 and 2021 editions of Section V of the ASME BPVC states: *Digital image acquisition, display, and storage can be applied to radiography and radioscopy. Once the analog image is converted to digital format, the data can be displayed, processed, quantified, stored, retrieved, and converted back to the original analog format, for example, film or video presentation.*	Radiographic examination requirements in Section V in the 2021 edition provide equivalent or greater safety to radiographic examination requirements in Section V in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		This requirement in Mandatory Appendix III only applies to digital image acquisition, display, and storage for radiography and radioscopy and not to digital radiography (DR) techniques as an alternative to film radiography. Rules in Paragraph IX-210 – Scope in Mandatory Appendix IX – Radiography Using Digital Detector Systems in the 2021 edition of Section V of the ASME BPVC specify requirements for the use of direct radiography (DR) techniques using digital detector systems (DDSs), where the image is transmitted directly from the detector rather than using an intermediate process for conversion of an analog image to a digital format. Mandatory Appendix IX also addresses applications in which the radiation detector, the source of the radiation, and the object being radiographed may or may not be in motion during exposure. Section V, Article 2 provisions apply unless modified by Mandatory Appendix IX. Radiography using digital detector systems as specified in Mandatory Appendix IX in the 2021 edition of Section V of the ASME BPVC is permitted as an alternative to digital image acquisition as provided in Mandatory Appendix III – Digital Image Acquisition, Display, and Storage for Radiography and Radioscopy in the 2007 and 2021 edition of Section V of the ASME BPVC. As noted above, the 2007 edition of Section V of the ASME BPVC does not include Mandatory Appendix IX – Application of Digital Radiography and Mandatory Appendix IX – Supplement A. Computed radiography (CR) and digital radiography (DR) are commonly used terms for digital radiographic detectors. Computed radiography uses a photostimulable storage phosphor that stores the latent image with subsequent processing using a stimulating laser beam and can be easily adapted to a cassette-based system analogous to that used in screen-film radiography. Historically, DR has been used to describe a digital X-ray imaging system that reads the transmitted X-ray signal immediately after exposure with the detector in place. Use of CR or DR provides equivalent or greater safety compared to use of film radiography and digital image acquisition provided NDE personnel are qualified and certified in the use of these methods. Rules for radiographic examination of welded joints are specified in Paragraph UW-51 – Radiographic Examination of Welded Joints in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. These rules state that all welds that require radiographic examination must be examined in accordance with rules specified in Article 2 – Radiographic Examination, Section V of the ASME BPVC, except as specified Paragraphs UW-51*(a)(1)* through *(a)(4)*.	

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
6.3.3	Ultrasonic Examination Requirements in Section V	Paragraph T-410 – Scope in Article 4 – Ultrasonic Examination Methods for Welds in the 2007 and 2021 editions of Section V of the ASME BPVC provides or references requirements for weld examinations. These requirements are used in selecting and developing ultrasonic examination procedures when examination to any part of this Article is a requirement of a referencing Code Section. These procedures are to be used for ultrasonic examinations and for dimensioning of indications for comparison with acceptance standards. Paragraph T-421 – Written Procedure Requirements states that ultrasonic examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table T-421 – Requirements of an Ultrasonic Examination Procedure or the Mandatory Appendices applicable to the technique in use. Product-specific, technique-specific, and application-specific requirements are also provided in the mandatory appendices in Section V, Article 4. Requirements provided in Article 4, Paragraph T-420 – General in the 2021 editions of Section V of the ASME BPVC were expanded from the 2007 edition to state: *The requirements of this Article shall be used together with Article 1, General Requirements. Refer to:* *(a) special provisions for coarse grain materials and welds in T-451* (provided in 2007 and 2021 editions) *(b) special provisions for computerized imaging techniques in T-452* (provided in 2007 and 2021 editions) *(c) Mandatory Appendix III for Time of Flight Diffraction (TOFD) techniques* (provided in 2021 edition) *(d) Mandatory Appendix IV for phased array manual rastering techniques* (provided in 2021 edition) *(e) Mandatory Appendix V for phased array E-scan and S-scan linear scanning examination techniques* (provided in 2021 edition) *(f) Mandatory Appendix XI for full matrix capture (FMC) techniques* (provided in 2021 edition) Paragraph 12-1*(b)* in Mandatory Appendix 12 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC states that Section V, Article 4 shall be applied for detail requirements in methods and procedures, unless otherwise specified in this Appendix.	Ultrasonic examination requirements in Section V in the 2021 edition provide equivalent safety to ultrasonic examination requirements in Section V in the 2007 edition.
6.3.4	Magnetic Particle Examination	Article 7 – Magnetic Particle Examination, Paragraph T-710 – Scope in the 2007 and 2021 editions of Section V of the ASME BPVC states that the magnetic particle examination techniques described in this Article must be used together with Article 1 – General Requirements when	Magnetic particle examination requirements in

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
	Requirements in Section V	specified by the referencing Construction Code. Requirements in T-721 – Written Procedure Requirements states that magnetic particle examination shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table T-721 – Requirements of a Magnetic Particle Examination Procedure. Additional magnetic particle examination requirements are provided in the 2021 editions of Article 7, Section V of the ASME BPVC in the mandatory appendices. Paragraph UG-103 – Nondestructive Testing in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC states that where magnetic particle examination is prescribed in this Division it shall be done in accordance with Mandatory Appendix 6 – Methods for Magnetic Particle Examination (MT). The rules for magnetic particle examination specified in Mandatory Appendix 6 state that Section V, Article 7 shall be applied for the detail requirements in methods and procedures, and the additional requirements specified within this Appendix.	Section V in the 2021 edition provide equivalent safety to magnetic particle examination requirements in Section V in the 2007 edition.
6.3.5	Liquid Penetrant Examination Requirements in Section	Article 6 – Liquid Penetrant Examination, Paragraph T-610 – Scope in the 2007 and 2021 editions of Section V of the ASME BPVC states that when this Article is specified by a referencing Code Section, the liquid penetrant method described in Article 6 shall be used together with Article 1 – General Requirements. Requirements in Paragraph T-621 – Written Procedure Requirements states that liquid penetrant examination shall be performed in accordance with a written procedure which shall as a minimum, contain the requirements listed in Table T-621.1 – Requirements of a Liquid Penetrant Examination Procedure. Additional liquid penetrant examination requirements are provided in the mandatory appendices. Paragraph UG-103 – Nondestructive Testing in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC states that where liquid penetrant examination is prescribed in this Division it shall be done in accordance with where liquid penetrant examination is prescribed in this Division it shall be done in accordance with Appendix 8 – Methods for Liquid Penetrant Examination (PT). The rules for liquid penetrant examination specified in Mandatory Appendix 8 state that Section V, Article 6 shall be applied for the detail requirements in methods and procedures, and the additional requirements specified within this Appendix.	Liquid penetrant examination requirements in Section V in the 2021 edition provide equivalent safety to liquid penetrant examination requirements in Section V in the 2007 edition.
6.3.6	Eddy Current Examination Requirements in Section V	Article 8 – Eddy Current Examination in the 2007 and 2021 editions of Section V of the ASME BPVC states that the eddy current examination method and techniques described in this Article shall be used when specified by the referencing Code Section. Additional eddy current examination requirements are provided in the 2021 editions of Article 8, Section V of the ASME BPVC in the mandatory appendices.	Eddy current examination requirements in Section V in the 2021 edition provide equivalent safety to

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		Requirements for eddy current examinations are not provided in either the 2007 or the 2021 edition of Section VIII, Division 1 of the ASME BPVC.	eddy current examination requirements in Section V in the 2007 edition.
6.3.7	Visual Examination Requirements in Section V	Article 9 – Visual Examination, Paragraph T-910 – Scope in the 2007 and 2021 editions of Section V of the ASME BPVC states that methods and requirements for visual examination in this Article are applicable together with requirements of Article 1 – General Requirements when specified by a referencing Construction Code. Specific visual examination procedures required for every type of examination are not included in this Article because there are many applications where visual examinations are required. Requirements in T-921 – Written Procedure Requirements states that visual examinations shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table T-921 – Requirements of a Visual Examination Procedure.	Visual examination requirements in Section V in the 2021 edition provide equivalent or greater safety to visual examination requirements in Section V in the 2007 edition.
7.1.2.1	Basis for Hydrostatic Pressure Testing Limits	Hydrostatic pressure testing rules for pressure vessels are specified in Paragraph UG-99 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. The rules specified in Paragraph UG-99*(b), (f)*, and *(k)* in the 2007 edition were expanded. The differences are discussed below. **<u>Paragraph UG-99*(b)*</u>** Hydrostatic testing rules specified in Paragraph UG-99*(b)* in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC state that the minimum hydrostatic test pressure, P_T, is equal to or greater than 1.3 MAWP times the LSR for the materials of which the pressure vessel is constructed. These rules state that the minimum hydrostatic test pressure shall be calculated using the following equation. $$P_T = 1.3 \text{ MAWP} \left(\frac{S_T}{S}\right)$$ However, Paragraph UG-99*(b)* in the 2021 edition of Section VIII, Division 1 of the ASME BPVC provides additional considerations that could affect the magnitude of the minimum hydrostatic test pressure. These additional considerations include the following. • Bolting shall not be included in the determination of the LSR, except when 1.3 times the LSR multiplied by the allowable stress of the bolt at its design temperature exceeds 90% of the bolt material specified minimum yield strength at the test temperature.	Hydrostatic pressure testing limits in the 2021 edition provide equivalent or greater safety to hydrostatic pressure testing limits in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		• The hydrostatic test pressure reading shall be adjusted to account for any static head conditions depending on the difference in elevation between the chamber being tested and the pressure gauge. **<u>Paragraph UG-99*(f)*</u>** Paragraph UG-99*(f)* in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC permits an internal hydrostatic or pneumatic pressure test of single-wall vessels and individual pressure chambers of combination units designed for vacuum only (MAWP less than or equal to zero). Either type of test shall be made at a pressure not less than 1.3 times the difference between normal atmospheric pressure and the minimum design internal absolute pressure. Paragraph UG-99*(f)(2)* in the 2021 edition also includes alternative rules for single-wall vessels and individual pressure chambers of combination units designed for vacuum only (MAWP less than or equal to zero). These alternative rules state that in conjunction with the vacuum test, a leak test shall be performed following a written procedure complying with the applicable technical requirements of Section V, Article 10 for the leak test method and technique specified by the user. Paragraph UG-99*(f)* in the 2021 edition further states that leak testing personnel shall be qualified and certified as required by Section V, Article 1, T-120*(e)*. Leak testing requirements prescribed in Section V, Article 10 are discussed in Sect. 6.4 of this report. **<u>Paragraph UG-99*(k)*</u>** Rules specified in Paragraph UG-99*(k)* in the 2007 edition of Section VIII, Division 1 of the ASME BPVC for painted and coated pressure vessel were revised and expanded in the 2021 edition. Paragraph UG-99*(k)* in the 2021 edition specifies conditions where pressure-retaining welds must remain uncoated or unpainted prior to pressure testing and when pressure-retaining welds must first be leak tested in accordance with Section V, Article 10. Rule in Paragraph UG-99 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC do not specify a minimum or maximum hydrostatic test pressure duration. Although the additional rules specified in Paragraph UG-99 in the 2021 edition of Section VIII, Division 1 of the ASME BPVC expand the scope of hydrostatic testing requirements provided in the 2007 edition, they do not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC.	

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
7.1.2.2	Basis for Pneumatic Pressure Testing Limits	Pneumatic pressure testing requirements for pressure vessels are specified in Paragraph UG-100 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. The rules specified in Paragraph UG-100*(b), (d), (e), (f)*, and *(g)* in the 2007 edition were expanded. The differences are discussed below. Based on the side-by-side comparation shown in Table 7.3, pneumatic pressure testing rules specified in Paragraph UG-100 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC are not the same. The differences are discussed below. **<u>Paragraph UG-100*(b)*</u>** According to rules specified in Paragraph UG-100*(b)*, the pneumatic test pressure, P_T, must be established based on the following conditions. • Minimum pneumatic test pressure, P_T, for the materials of which the pressure vessel is constructed is based on rules specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. These rules state that the minimum pneumatic test pressure shall be calculated using the following equation. $$P_T = 1.1\text{ MAWP}\left(\frac{S_T}{S}\right)$$ • Maximum P_T is not specified in either the 2007 or 2021 edition of Section VIII, Division 1 of the ASME BPVC. However, rules specified in the 2007 and 2021 editions state that in no case shall the pneumatic test pressure exceed 1.1 times the basis for the calculated test pressure as defined in Mandatory Appendix 3-2. The calculated test pressure, P_T, is defined in Mandatory Appendix 3 – Definitions, Paragraph 3-2 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. This definition states that the requirements for determining the test pressure based on calculations are outlined in UG-99*(c)* for the hydrostatic test and in UG-100*(b)* for the pneumatic test. The basis for calculated test pressure in either of these paragraphs is the highest permissible internal pressure as determined by the design formulas, for each element of the vessel using nominal thicknesses with corrosion allowances included and using the allowable stress values given in Section II, Part D, Tables 1A and 1B, as applicable, of the ASME BPVC for the temperature of the test (See Sect. 4.4.1 of the report).	Pneumatic pressure testing limits in the 2021 edition provide equivalent or greater safety to pneumatic pressure testing limits in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
		<u>Paragraph UG-100*(d)*</u> Rules specified in Paragraphs UG-100*(d)* in the 2021 editions are subdivided and expanded to include separate rules for independent pressure chambers and dependent pressure chambers. **<u>Paragraph UG-100*(e)*</u>** Rules specified in Paragraphs UG-100*(e)* in the 2021 edition provide conditions for waving the required visual examination at the test pressure. These rules were not included in the 2007 edition. **<u>Paragraph UG-100*(f)*</u>** Rules specified in Paragraphs UG-100*(e)* in the 2007 edition correspond to revised rules for painting and coating specified in the UG-100*(f)* in the 2021 edition. Rules specified in Paragraph UG-100*(f)* were not included in the 2007 edition. Paragraph UG-100*(f)(2)* in the 2021 edition states that when painting or coating prior to the pneumatic test is permitted, or when internal nonmetallic linings are to be applied, the pressure-retaining welds shall first be leak tested in accordance with Section V, Article 10. Such a test may be waived with the approval of the user or his designated agent. Leak testing requirements prescribed in Section V, Article 10 are discussed in Sect. 6.4 of this report. **<u>Paragraph UG-100*(g)*</u>** Rules specified in Paragraphs UG 100*(g)* in the 2021 edition for custom-designed flange assemblies were not included in the 2007 edition. Rules in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC do not specify a minimum or maximum pneumatic test pressure duration. The rules state that the pressure must be held for sufficient time to permit inspection of the pressure vessel. Although the additional rules specified in Paragraph UG-100 expand the scope of hydrostatic testing requirements provided in the 2021 edition of Section VIII, Division 1 of the ASME BPVC, they do not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC.	
7.2	Alternative Pressure Testing	The 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC do not include alternative pressure testing requirements.	An equivalent safety evaluation of alternative pressure testing requirements in

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Determination
			the 2007 and 2021 editions is not possible.
7.3.2	Proof Testing	Requirements for proof testing to establish MAWP are provided in Paragraph UG-101 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. Provision is made in these rules for two types of tests to determine the internal maximum allowable working pressure: 1. tests based on yielding of the part to be tested. These tests are limited to materials with a ratio of minimum specified yield to minimum specified ultimate strength of 0.625 or less. 2. tests based on bursting of the part. Requirements for permitted proof test procedures are specified in the following paragraphs in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. • Paragraph UG-101(*l*) – Brittle-Coating Test Procedure • Paragraph UG-101(*m*) – Bursting Test Procedure • Paragraph UG-101(*n*) – Strain Measurement Test Procedure • Paragraph UG-101(*o*) – Displacement Measurement Test Procedure • Paragraph UG-101(*p*) – Procedure for Vessels Having Chambers of Special Shape Subject to Collapse Selection of a particular proof test procedure depends on its applicability to the type of loading and to the material used in construction. It is important to note that the corresponding proof test equations in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC for computing MAWP using test data are the same.	The proof testing requirements in the 2021 edition provide equivalent safety to the proof testing requirements in the 2007 edition
8.2	Overpressure Protection by Pressure Relief Device	All Section VIII, Division 1 pressure relief device requirements have been transferred from Paragraphs UG-125 through UG-140 to Section XIII – Rules for Overpressure Protection and the remaining Division 1 overpressure protection requirements have been restructured within the new Paragraphs UG-150 through UG-156. See Nonmandatory Appendix PP – Guide to the Relocation of Overpressure Protection Requirements in Section VIII, Division 1 for a complete cross-reference list. New locations for all requirements formerly located in UG-125 through UG-140 are provided in Table PP-1-1. Paragraph UG-150 – General Requirements states: *(a)* UG-150 through UG-155 provide the acceptable methods and requirements for overpressure protection for pressure vessels constructed to the requirements of this Division. Acceptable methods include pressure relief devices, open flow paths, and overpressure protection by system design. Paragraph UG-150 specifies the type, quantity and settings of acceptable pressure relief devices and relieving capacity requirements including maximum allowed relieving pressures.	Due to restructuring of paragraphs in the 2021 edition and transferring to Section XIII, a comprehensive equivalent safety evaluation of overpressure protection rules between the 2007 and 2021 edition of Section VIII, Division 1 of the

<table>
<tr><th>Reference section of this report</th><th>Rule or Requirement</th><th>Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 1 of the ASME BPVC</th><th>Equivalent Safety Determination</th></tr>
<tr><td></td><td></td><td>Paragraph UG-153(a)(2) – Overpressure Limits states: when a pressure vessel can be exposed to fire or other unexpected sources of external heat, the pressure relief device(s) must be capable of preventing the pressure from rising more than 21% above the MAWP. (i.e., 1.21 MAWP).</td><td>ASME BPVC was not performed.</td></tr>
<tr><td>8.2</td><td>Overpressure Protection by System Design</td><td>Paragraph UG-154(e) states that overpressure protection by system design in accordance with Section XIII, Part 13 is permitted under the following conditions.
For vessels with overpressure protection by system design where the pressure is self-limited at or below the vessel MAWP, (see Section XIII, 13.2), there shall be no credible overpressure scenario in which the pressure exceeds the maximum allowable working pressure (MAWP) of the pressurized equipment at the coincident temperature.
For vessels with overpressure protection by system design where the pressure is not self-limited at or below the vessel MAWP, (see Section XIII, 13.3):
a. there shall be no credible overpressure scenario in which the pressure exceeds 116% of the MAWP times the ratio of the allowable stress value at the temperature of the overpressure scenario to the allowable stress value at the vessel design temperature.
b. the overpressure limit shall not exceed the vessel test pressure.</td><td>Due to restructuring of paragraphs in the 2021 edition and transferring to Section XIII, a comprehensive equivalent safety evaluation of overpressure protection rules between the 2007 and 2021 edition of Section VIII, Division 1 of the ASME BPVC was not performed.</td></tr>
</table>

Table 9.3 Evaluation of equivalent safety for rules and requirements specified in the 2021 edition of Section VIII, Division 2 compared to correspond rules and requirements specified in the 2007 edition of Section VIII, Division 2 of the ASME BPVC

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
4.1.1.3	Excessive Elastic Deformation and Elastic Instability	Excessive elastic deformation (deflection) and elastic instability (buckling) cannot be controlled by imposing upper limits to the calculated stress alone because these behavioral phenomena are affected by component geometry and stiffness and material properties. Excessive elastic deformation can occur when a component with inadequate stiffness experiences unwanted flexibility or unacceptable deflections. Buckling is characterized by a sudden sideways failure of a component subjected to high compressive stress, where the compressive stress at the point of failure is less than the ultimate compressive stress that the material is capable of withstanding. The designer of a boiler or pressure vessel is responsible for applying engineering principles to understand and avoid in-service problems or failures caused by excessive elastic deformation and elastic instability. Three alternative types of buckling analyses are included in Part 5, Paragraph 5.4 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC to evaluate structural stability from compressive stress fields. The design factor to be used in a structural stability assessment is based on the type of buckling analysis performed. These design factors are the same in the 2007 and 2021 editions. Minimum design factors are provided for use with shell components when the buckling loads are determined using a numerical solution (i.e., bifurcation buckling analysis or elastic-plastic collapse analysis). Bifurcation buckling is defined as the point of instability where there is a branch in the primary load versus displacement path for a structure. Unlike rules specified in Section VIII, Division 1, these buckling analyses do not reference the external pressure charts provided in Section II, Part D, Mandatory Appendix 3 in the 2007 and 2021editions of the ASME BPVC.	Excessive elastic deformation and elastic instability requirements in the 2021 edition provide equivalent or greater safety compared to excessive elastic deformation and elastic instability requirements in the 2007 edition.
4.1.2	Excessive Plastic Deformation	The plastic deformation mode of failure (ductile rupture) is controlled by imposing limits on calculated stress. Primary stress limits and primary plus secondary stress limits in the ASME BPVC are intended to prevent excessive plastic deformation leading to incremental collapse and to provide a nominal margin on the ductile burst pressure. The designer of a boiler or pressure vessel is responsible for ensuring that the specified stress limits are not exceeded under the operating conditions defined by the user. Rules for avoiding excessive plastic deformation are provided in Part 5, Paragraph 5.2 in the 2007 and 2021editions of Section VIII, Division 2 of the ASME BPVC. As discussed in Sect. 4.4.2 and 4.4.5 of this report, the maximum allowable membrane stress, P_m, for pressure vessels constructed in accordance with rules specified in the 2007 and 2021editions of Section VIII, Division 2 is limited to two-thirds of the yield strength, 2/3 S_y, or less. Rules specified in the 2007 and	Excessive plastic deformation requirements in the 2021 edition provide equivalent safety compared to excessive plastic deformation requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		2021editions of Section VIII, Division 2 also ensure that the primary membrane stress plus the primary bending stress, $P_m + P_b$, does not exceed S_y. Based on the principles of limit design theory discussed in Sect. 4.6 of this report, these rules provide a minimum design margin against plastic collapse equal to or greater than 1.5. Additional discussion about protection against plastic collapse is presented in Sect. 4.8 of this report.	
4.1.3.3	Brittle Fracture	The ability of a metal to resist tearing or cracking is a measure of its fracture toughness. In fracture mechanics calculations, the value of the stress intensity factor, K_I, is based on the applied stress and dimensions of the flaw. To avoid brittle fracture, the calculated K_I must be less than the critical fracture toughness parameter, K_{Ic}. From an equivalency viewpoint, an increase in the maximum allowable design stress for a material with a critical flaw size requires an increase in fracture toughness to maintain the same margin against brittle fracture. In addition, increasing fracture toughness reduces the risk that critical flaw sizes below the NDE detection limits do not result in brittle fracture. Rules in Part 3 Materials Requirements, Paragraph 3.11 – Material Toughness Requirements in the 2007 and 2021 specify separate requirements for the following material groups. *(a)* Toughness requirements for materials listed in Table 3-A.1 (carbon and low alloy steel materials except bolting materials) are given in Paragraph 3.11.2. *(b)* Toughness requirements for materials listed in Table 3-A.2 (quenched and tempered steels with enhanced tensile properties) are given in Paragraph 3.11.3. *(c)* Toughness requirements for materials listed in Table 3-A.3 (high alloy steels except bolting materials) are given in Paragraph 3.11.4. *(d)* Toughness requirements for materials listed in Table 3-A.4 through 3-A.7 (nonferrous alloys) are given in Paragraph 3.11.5. *(e)* Toughness requirements for all bolting materials are given in Paragraph 3.11.6. Toughness requirements for these material groups are the same in the 2007 and 2021editions of Section VIII, Division 2 of the ASME BPVC expect for materials listed in Table 3-A.1. For materials listed in Table 3-A.1, the minimum lateral expansion values permitted in the 2021 edition are approximately 30% greater than the minimum lateral expansion values permitted in the 2007 edition of Section VIII, Division 2 of the ASME BPVC. Consequently, toughness requirements in the 2021 edition of Section VIII, Division 2 of the ASME BPVC for materials listed in Table 3-A.1 are more stringent than those in the 2007 edition for materials listed in Table 3-A.1. The explanation for this change, which was adopted in the 2008 Addenda, follows.	Requirements in the 2021 edition for protection against brittle fracture provide equivalent or greater safety compared to requirements in the 2007 edition for protection against brittle fracture.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		In the 2007 editions the toughness rules for high-strength steels with ultimate tensile strength greater than 95 ksi was the same as was published in the prior edition, even though the allowable design stress for these materials can be higher by a factor of 1.25. Analytical work was performed to assess the toughness requirements of these materials, and as a result of this work the lateral expansion shown in Figures 3.6 and 3.6M were revised resulting in an average increase of approximately 30%	
4.1.4.2	Stress Rupture and Creep Deformation	Boiler and pressure vessel materials that are in service above a certain temperature undergo continuing deformation (creep) at a rate that is strongly influenced by both stress and temperature. The temperature at which creep occurs varies with the alloy composition. To prevent excessive deformation and possible premature rupture it is necessary to limit the allowable stresses by additional criteria on creep-rate and stress-rupture. Criteria for establishing allowable stress values for Tables 2A and 2B and Table 5A and 5B are provided in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC. These criteria, which are discussed in Sect. 4.4.24.4.5 and 4.4.5 of this report, cover temperatures in the range where creep and stress rupture strength govern the selection of stresses. The criteria for establishing allowable stress values for Tables 2A and 2B and Table 5A and 5B that are provided in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC are the same.	Stress rupture and creep deformation requirements in the 2021 edition provide equivalent safety compared to stress rupture and creep deformation requirements in the 2007 edition.
4.1.5.3	Plastic Instability – Incremental Collapse	Ratcheting is defined as a progressive incremental inelastic deformation or strain that can occur in a component subjected to variations of mechanical stress, thermal stress, or both. Ratcheting is produced by a sustained load acting over the full cross section of a component, in combination with a strain controlled cyclic load or temperature distribution that is alternately applied and removed. Ratcheting results in cyclic straining of the material, which can result in failure by fatigue and at the same time produces cyclic incremental deformation of a component, which may ultimately lead to collapse. Rules for ratcheting assessments are specified in Part 5, Paragraphs 5.5.6 – Ratcheting Assessment — Elastic Stress Analysis and 5.5.7 – Ratcheting Assessment — Elastic–Plastic Stress Analysis in the 2007 and 2021editions of Section VIII, Division 2 of the ASME BPVC. Protection against ratcheting must be considered for all operating loads listed in the User's Design Specification and must be performed even if the fatigue screening criteria are satisfied (see 5.5.2). Protection against ratcheting is satisfied if one of the following three conditions is met: 1. The loading results in only primary stresses without any cyclic secondary stresses.	Plastic instability and incremental collapse requirements in the 2021 edition provide equivalent safety compared to plastic instability and incremental collapse requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		2. Elastic Stress Analysis Criteria – Protection against ratcheting is demonstrated by satisfying the rules of 5.5.6. 3. Elastic–Plastic Stress Analysis Criteria – Protection against ratcheting is demonstrated by satisfying the rules of 5.5.7. The rules for ratcheting assessments specified in Part 5, Paragraphs 5.5.6 and 5.5.7 are the same in the 2007 and 2021editions of Section VIII, Division 2 of the ASME BPVC.	
4.1.6.3	Fatigue	Rules for performing a fatigue screening are specified in Paragraph 5.5.2 – Screening Criteria for Fatigue Analysis in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. These criteria are subdivided into the following four categories. • Fatigue Analysis Screening Based on Experience with Comparable Equipment • Fatigue Analysis Screening, Method A • Fatigue Analysis Screening, Method B Rules for performing a fatigue evaluation are specified in the following Paragraphs in the 2007 and 2021editions of Section VIII, Division 2 of the ASME BPVC. • Paragraph 5.5.3 – Fatigue Assessment – Elastic Stress Analysis and Equivalent Stresses. In this method, an effective total equivalent stress amplitude is used to evaluate the fatigue damage for results obtained from a linear elastic stress analysis. • Paragraph 5.5.4 – Fatigue Assessment – Elastic Plastic Stress Analysis and Equivalent Strains. In this method, the effective strain range is used to evaluate the fatigue damage for results obtained from an elastic–plastic stress analysis. • Paragraph 5.5.5 – Fatigue Assessment of Welds – Elastic Analysis and Structural Stress. In this method, an equivalent structural stress range parameter is used to evaluate the fatigue damage for results obtained from a linear elastic stress analysis. The rules for performing a fatigue screening and fatigue evaluation are the same in the 2007 and 2021editions of Section VIII, Division 2 of the ASME BPVC.	Fatigue requirements in the 2021 edition provide equivalent safety compared to fatigue requirements in the 2007 edition.
4.1.7.3	Stress Corrosion and Corrosion Fatigue	Two common types of corrosion that can adversely affect the integrity of a boiler or pressure vessel include stress corrosion cracking and corrosion fatigue. Stress corrosion cracking (SCC) is the growth of crack formation in a corrosive environment and is highly chemically specific in that certain alloys are likely to undergo SCC only when exposed to a small number of chemical environments. Corrosion fatigue is the mechanical degradation of a material under the joint action of corrosion and cyclic loading. Since corrosion-fatigue cracks initiate at a metal's surface, surface treatments like plating, cladding, nitriding, and shot peening can improve the materials' resistance to corrosion fatigue. However, corrosion fatigue only occurs when the metal is under tensile stress.	Stress corrosion cracking and corrosion fatigue requirements in the 2021 edition provide equivalent or greater safety compared to stress corrosion cracking and corrosion

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		Rules specified in Part 4, Paragraph 4.1.4.2 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC state: *The term corrosion allowance as used in this Division is representative of loss of metal by corrosion, erosion, mechanical abrasion, or other environmental effects and shall be accounted for in the design of vessels or parts when specified in the User's Design Specification.* Requirements in Part 2 – Responsibilities and Duties, Paragraph 2.2.3.1*(f)* – Design Fatigue Life in the 2021 edition of Section VIII, Division 2 of the ASME BPVC states that a User's Design Specification shall include corrosion fatigue. If corrosion fatigue is anticipated, a factor should be chosen on the basis of experience or testing, by which the calculated design fatigue cycles (fatigue strength) should be reduced to compensate for the corrosion.	fatigue requirements in the 2007 edition.
4.2.3	Design Basis	Rules specified in Paragraph 2.2.1 in Part 2 – Responsibilities and Duties in the 2021 edition of Section VIII, Division 2 of the ASME BPVC states that it is the responsibility of the user or an agent acting on behalf of the user to provide a User Design Specification (UDS) for each pressure vessel to be constructed in accordance with this Division. The UDS must contain sufficient detail to provide a complete basis for design and construction in accordance with this Division including design loads and load case combinations described in Paragraph 4.1.5.3 – Design Loads and Load Case Combinations. According to requirements provided in Paragraph 4.1.5.3, all applicable loads and load case combinations shall be considered in the design to determine the minimum required wall thickness for a vessel part. The loads that shall be considered in the design shall include, but not be limited to, those shown in Table 4.1.1 – Design Loads and shall be included in the User's Design Specification. The load combinations that shall be considered shall include, but not be limited to, those shown in Table 4.1.2, except when a different recognized standard for wind loading is used. In that case, the User's Design Specification shall cite the Standard to be applied and provide suitable load factors if different from ASCE/SEI 7 [10]. The factors for wind loading, W, in Table 4.1.2, Design Load Combinations, are based on ASCE/SEI 7 wind maps and probability of occurrence. If a different recognized standard for earthquake loading is used, the User's Design Specification shall cite the Standard to be applied and provide suitable load factors if different from ASCE/SEI 7. Loads due to deflagration were not included in Table 4.1.1 in the 2007 edition but are included in Table 4.1.1 in the 2021 edition of Section VIII, Division 2 of the ASME BPVC. Guidance to accommodate loadings produced by deflagration are provided in Annex 4-D in the 2021 edition of Section VIII, Division 2 of the ASME BPVC. It is the user's responsibility to	Design basis requirements in the 2021 edition provide equivalent or greater safety compared to design basis requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		specify, or cause to be specified, the effective Code edition and vessel class to be used for construction. According to the following requirements specified in the 2021 edition of Section VIII, Division 2 of the ASME BPVC: • Paragraph 2.2.2.1, the UDS for a Class 1 pressure vessel shall be certified by a Certifying Engineer meeting the requirements described in Annex 2-A – Guide for Certifying a User's Design Specification when the user provides the data in the USD required to perform a fatigue analysis. • Paragraph 2.2.2.2, the UDS for a Class 2 pressure vessel shall be certified by a Certifying Engineer in accordance with Annex 2-A – Guide for Certifying a User's Design Specification. When required by Paragraph 2.2.2.1 or 2.2.2.2, certification of the UDS requires the signature(s) of one or more Certifying Engineers with requisite experience and qualifications as defined in Annex 2-J – Qualifications and Requirements for Certifying Engineers and Designers. As discussed on Sect. 2.3 of this report, the 2007 edition of Section VIII, Division 2 of the ASME BPVC states that one or more Professional Engineers, registered in one or more of the states of the United States of America or the provinces of Canada and experienced in pressure vessel design, shall certify that the UDS meets the requirements in Paragraph 2.2.2, and shall apply the Professional Engineer seal in accordance with the required procedures.	
4.4.2, 4.4.3, 4.4.4, and 4.4.5	Allowable Stress Values	Criteria for establishing design stress intensity values in Table 2A and 2B are provided in Mandatory Appendix 2, Table 2-100*(a)* in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC. Tables 2A and 2B provide design stress intensity values for materials permitted for Section VIII, Division 2, Class 1 construction. Criteria for establishing allowable stress values in Table 3 are provided in Mandatory Appendix 2, Table 2-120*(a)* in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC. Table 3 provides allowable stress values for bolting materials for use in Section VIII, Division 1 and Section VIII, Division 2 (using Part 4.16 of Section VIII, Division 2) construction. Criteria for establishing design stress intensity values in Table 4 are provided in Mandatory Appendix 2, Table 2-130*(a)* in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC. Table 4 provides design stress intensities for bolting materials used in Section VIII, Division 2 (using Part 5 and Annex 5.F of Section VIII, Division 2) construction.	Allowable stress rules in the 2021 edition provide equivalent safety to allowable stress rules in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		Criteria for establishing maximum allowable stress values for Tables 5A and 5B are provided in Section II, Mandatory Appendix 10, Table 10-100 in Section II, Part D of the 2007 and 2021 editions of the ASME BPVC. Table 5A and Table 5B provide maximum allowable stress values for construction of Class 2 vessels in accordance with rules specified in Annex 3-A – Allowable Design Stresses in Section VIII, Division 2 in the 2021 edition of the ASME BPVC. The criteria for establishing allowable stress values provided in Mandatory Appendix 2 and 10 are the same in the Section II, Part D of the 2007 and 2021 editions of the ASME BPVC. Unlike Section VIII, Division 1 of the ASME BPVC, there are no rules in Section VIII, Division 2 of the ASME BPVC specifically for pressure vessels constructed using materials having higher allowable stresses at low temperature. The maximum allowable design stress values published in Tables 2A. 2B, 5A, and 5B the 2007 and 2021 editions of Section II, Part D of the ASME BPVC are based on the following stress limits as discussed in Sect. 4.6 of this report. $P_m \leq S_y$ Stress limit {4.5} $P_m + P_b \leq 1.5S_y$ Stress limit {4.6} Adequate safety against plastic collapse for pressure vessels constructed in accordance with rules specified in the 2007 and 2021 editions of Section VIII, Divisions 1 and 2 is achieved by limiting design stresses to 2/3 of these stress limits as stated in Equations {4.7} and {4.8}. $P_m \leq 0.67S_y$ Design stress limit {4.7} $P_m + P_b \leq 1.0S_y$ Design stress limit {4.8}	
4.5.2	Section VIII, Division 2 Design-by-Rule Strength Theory	Design-by-rule requirements provided in Part 4 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC are based on the maximum shear stress theory, which is also known as the Tresca yield criterion, discussed in Sect. 4.5.2 of this report.	Design-by-rule requirements in the 2021 edition provide equivalent safety to design-by-rule requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
4.5.3	Section VIII, Division 2 Design-by-Analysis Strength Theory	Design-by-analysis requirements provided in Part 5 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC are based on the distortion energy theory using the von Mises yield criterion discussed in Sect. 4.5.3 of this report. Most experiments show that the distortion energy theory (von Mises) is more accurate than the shear theory (Tresca) because ductile materials behave closer to the von Mises yield criterion. However, the Tresca yield criterion gives a more conservative estimate on failure compared to the von Mises yield criterion. Under the same loading conditions, principle stresses determined using the Tresca yield criterion are approximately 15% more than the principle stresses determined using the von Mises yield criterion. Even though the maximum difference between the von Mises and Tresca yield criteria is only about 15%, this difference represents a systemic error (divergence) on the part of the Tresca yield criterion.	Design-by-analysis requirements in the 2021 edition provide equivalent or greater safety compared to design-by-analysis requirements in the 2007 edition.
4.7	Stress Range for Repetitively Applied Loads	Shakedown of a component occurs if, after a few cycles of load application, ratcheting ceases. The subsequent structural response is elastic or elastic-plastic, and progressive incremental inelastic deformation is absent. Elastic shakedown is the case in which the subsequent response is elastic. The ASME BPVC limits localized discontinuity stresses to 3.0 times the maximum allowable stress value in tension or 2.0 times the minimum specified tensile yield stress, S_y, of the material provided the allowable stress is not governed by time-dependent properties of the material and the room temperature ratio of the specified minimum yield strength, S_y, to specified minimum tensile strength, S_u, for the material does not exceed 0.7. This requirement ensures the material has strain-hardening properties sufficient to prevent material failure if the primary stress exceeds the yield strength of the material through the entire thickness. Further discussion about stress range for repetitively applied loads are presented in Sect. 4.7 of this report. Rules in Paragraph 5.5.6*(d)* in the 2007 edition and Paragraph 4.1.6.3 in the 2021 edition of Section VIII, Division 2 in the ASME BPVC limits the allowable primary plus secondary stress range, S_{PS}, to 3.0 times the maximum allowable stress value in tension or 2.0 times the minimum specified yield strength, S_y, of the material as follows: $$S_{PS} = \max[3S, 2S_y]$$ However, S_{PS} shall be limited to $3S$ if either (a) the room temperature ratio of the minimum specified yield strength from Annex 3-D to the ultimate tensile strength from Annex 3-D exceeds 0.70; or, (b) the allowable stress from Annex 3-A is governed by time-dependent properties.	Rules for stress range for repetitively applied loads in the 2021 edition provide equivalent safety to rules for stress range for repetitively applied loads in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
4.8.2	Plastic Collapse Stress Limits	Plastic collapse is the load at which overall structural instability occurs. The collapse load is the maximum load limit for a component made of elastic perfectly plastic material. Deformations of these components increase without bound at the collapse load. As discussed in Sect. 4.4.2 and 4.4.5 of this report, rules specified in Part 4, Paragraph 4.1.6.1 in the 2007 and 2021 editions of Section VIII, Division 2 ensure that the maximum allowable primary membrane stress, P_m, does not exceed $2/3S_y$ and that the maximum allowable primary membrane stress plus primary bending stress, $P_m + P_b$, does not exceed S_y. These maximum allowable stress limits are consistent with the plastic collapse stress limits discussed in Sect. 4.6 of this report. Three alternative analysis methods are provided in Part 5, Paragraph 5.2 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC for evaluating protection against plastic collapse. Brief descriptions of these analysis methods follow. 1. Elastic Stress Analysis Method – Stresses are computed using an elastic analysis, classified into categories, and limited to allowable values that have been conservatively established such that a plastic collapse will not occur. 2. Limit-Load Method – A calculation is performed to determine a lower bound to the limit load of a component. The allowable load on the component is established by applying design factors to the limit load such that the onset of gross plastic deformations (plastic collapse) will not occur. 3. Elastic-Plastic Stress Analysis Method – A collapse load is derived from an elastic-plastic analysis considering both the applied loading and deformation characteristics of the component. The allowable load on the component is established by applying design factors to the plastic collapse load. For components with complex geometries and loadings, the categorization of stresses requires significant knowledge and judgment by the analyst. This is especially true for three-dimensional stress fields [6].	Plastic collapse stress limit rules in the 2021 edition provide equivalent safety to plastic collapse stress limit rules in the 2007 edition
4.9.3	Design-by-Rule	Basic requirements for application of the design-by-rules methods for pressure vessel are provided in Part 4 – Design by Rule Requirements in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. These requirements provide design rules for commonly used pressure vessel shapes under pressure loading and, within specified limits, rules, or guidance for treatment of other loadings. Beginning with the 2007 edition of Section VIII, Division 2 of the ASME BPVC, the specified design-by-rule equations in Part 4 are based on a limit analysis using the maximum shear stress theory discussed on Sect. 4.5.2 of this report. Rules specified in Paragraph 4.1.5.1.1 in the	Design-by-rule requirements in the 2021 edition provide equivalent or greater safety compared to design-by-rule

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		2021 edition state that the design-by-rule methods of Part 4 shall be applied using the load and load case combinations for the design of Class 1 construction. Part 4 does not provide rules to cover all loadings, geometries, and details. When design rules are not provided for a pressure vessel or pressure vessel part, a stress analysis in accordance with Part 5 – Design by Analysis Requirements must be performed considering all of the loadings specified in the User's Design Specification. The design procedures in Part 4 may be used if the allowable stress at the design temperature is governed by time-independent or time-dependent properties unless otherwise noted in a specific design procedure. When the pressure vessel is operating at a temperature where the allowable stress is governed by time-dependent properties, the effects of joint alignment and weld peaking in shells and heads must be considered.	requirements in the 2007 edition.
4.10	Design-by-Analysis	Rules for the design-by-analysis methods are specified in Part 5 – Design by Analysis Requirements in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. Detailed design procedures utilizing the results from a stress analysis are provided to evaluate components for plastic collapse, local failure, buckling, and cyclic loading. Supplemental requirements are provided for the analysis of bolts, perforated plates, and layered vessels. Procedures are also provided for design using the results from an experimental stress analysis, and for fracture mechanics evaluations. The design-by-analysis methods is used to design Class 2 pressure vessels that are consistent with allowable stress values in Table 5A or Table 5B in Section II, Part D of the ASME BPVC as discussed in Sect. 4.4.5 of this report. The design-by-analysis requirements are organized based on protection against the failure modes listed below. The component is evaluated for each applicable failure mode. If multiple assessment procedures are provided for a failure mode, only one of these procedures must be satisfied to qualify the design of a component. • Protection Against Plastic Collapse – these requirements apply to all components where the thickness and configuration of the component is established using design-by-analysis rules. • Protection Against Local Failure – these requirements apply to all components where the thickness and configuration of the component is established using design-by-analysis rules. It is not necessary to evaluate the local strain limit criterion if the component design is in accordance with the component wall thickness and weld details of Part 4. • Protection Against Collapse from Buckling – these requirements apply to all components where the thickness and configuration of the component is established using design-by-analysis rules and the applied loads result in a compressive stress field.	Design-by-analysis rules in the 2021 edition provide equivalent or greater safety compared to design-by-analysis rules in the 2007 edition.

<table>
<tr><th>Reference section of this report</th><th>Rule or Requirement</th><th>Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC</th><th>Equivalent Safety Determination</th></tr>
<tr><td></td><td></td><td>Protection Against Failure from Cyclic Loading – these requirements apply to all components where the thickness and configuration of the component is established using design-by-analysis rules and the applied loads are cyclic. In addition, these requirements can also be used to qualify a component for cyclic loading where the thickness and size of the component are established using the design-by-rule requirements of Part 4.
Beginning with the 2007 edition of Section VIII, Division 2 of the ASME BPVC, the specified design-by-analysis equations in Part 5 are based on a limit analysis using the distortion energy theory (also known as the octahedral shear theory and the von Mises criterion) given by Equation {4.3} in Sect. 4.5.3 of this report.</td><td></td></tr>
<tr><td>5.1.3</td><td>Forming Deviations</td><td>Rules for forming shell sections and heads are specified in Part 6 – Fabrication Requirements, Paragraph 6.1.2 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. These rule cover forming of carbon and low alloy steels, high alloy steel parts, nonferrous material parts, lugs and fitting attachments, and spin-holes. Equations for determining extreme fiber elongation are specified in Table 6.1 – Equations for Calculating Forming Strains. Table 6.2 – Post Fabrication Strain Limits and Required Heat Treatment for High Alloy Materials in the 2007 edition was reorganized into Tables 6.2.A and 6.2.B in the 2021 edition as follows.
Tables 6.2.A Post-Cold-Forming Strain Limits and Heat-Treatment Requirements for P-No. 15E Materials
Tables 6.2.B Post-Fabrication Strain Limits and Required Heat Treatment for High Alloy Materials
Post-fabrication strain limits and required heat treatment for nonferrous materials are specified in Table 6.3 – Post Fabrication Strain Limits and Required Heat Treatment for Nonferrous Materials.</td><td>Forming deviations in the 2021 edition provide equivalent or greater safety to forming deviations in the 2007 edition.</td></tr>
<tr><td>5.2.1.3</td><td>Formed Head Tolerances</td><td>Paragraph 4.3.2 – Shell Tolerances in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC specifies rules for shells of completed vessels and for formed heads.
Paragraph 4.3.2.3 in the 2007 and 2021 editions states that shells that do not meet the tolerance requirements of this paragraph may be evaluated using Paragraph 4.14 – Evaluation of Vessels Outside of Tolerance.

Paragraph 4.4.4.1 – Permissible Out-of-Roundness of Cylindrical and Conical Shells in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC states that a shell of a completed vessel subject to external pressure shall meet the following requirements at any cross section.
(a) The out-of-roundness requirements in 4.3.2.1 shall be satisfied.
(b) The maximum plus or minus deviation from a true circle, e, measured from a segmental circular template having the design inside or outside radius (depending on where the measurements are taken) and a chord length should not exceed the following value.</td><td>Formed head tolerances in the 2021 edition provide equivalent safety to formed head tolerances in the 2007 edition.</td></tr>
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Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
5.2.2.3	Alignment Tolerances	Rules for alignment tolerances for edges to be butt welded are specified in Part 6, Paragraph 6.1.6 – Alignment Tolerances for Edges to be Butt Welded in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. Paragraph 6.1.6.3 – Peaking of Welds in Shells and Heads for Internal Pressure was revised in the 2021 edition to state: If the vessel is operating at a temperature where the allowable stress is governed by time-dependent properties, see 4.1.1.3, or if a fatigue analysis is required, see 4.1.1.4, then the peaking height, P_d, at Category A weld joints shall be measured by either an inside or outside template, as appropriate (See Figure 6.1). As an alternative, the peaking angle may be determined using the procedure described in Part 8 of API 579-1/ASME FFS-1 [9]. This rule change applies to vessel that operate at a temperature where the allowable stress is governed by time-dependent properties.	Alignment tolerances in the 2021 edition provide equivalent or greater safety to alignment tolerances in the 2007 edition.
5.3.1	Base Metal Groupings	P-Numbers are assigned to base metals for the purpose of reducing the number of required welding and brazing procedure qualifications. P-Numbers for the same base metal are different for welding and brazing. Paragraph PG-5.6 in Section I of the 2021 edition of the ASME BPVC specifies rules that permit use of P-No. 15E, Group 1 materials for boiler construction. Section I in the 2007 edition of the ASME BPVC did not include Paragraph PG-5.6 (see Paragraph PG-5 in Table 9.2 of this report).	P-Numbers in the 2021 edition provide equivalent safety to P-Numbers in the 2007 edition.
5.3.2	Welding and Brazing Methods	Rules for welding and brazing are specified in Part QW and Part QB, respectively, in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for plastic fusing are only specified in Part QF in the 2021 edition of Section IX of the ASME BPVC. All of the welding and brazing methods permitted in the 2007 edition are also permitted in the 2021 edition. However, Diffusion Welding (DFW), Low-Power Density Laser Beam Welding (LLBW), and Friction Stir Welding (FSW) are also permitted in the 2021 edition.	Welding and brazing methods in the 2021 edition provide equivalent safety to welding and brazing methods in the 2007 edition. Fusing method rules are not specified in the 2007 edition.
5.3.3	Rules in Section IX for Procedure Specification	A Procedure Specification addresses the conditions (including ranges, if any) under which the material joining process must be performed. These conditions are referred to as “variables.” When a Procedure Specification is prepared by the organization, it must address, as a minimum, the specific essential and nonessential variables that are applicable to the material joining process to be used in production. When toughness qualification of the material joining procedure is required, the applicable supplementary essential variables must also be addressed in the Procedure Specification.	Procedure specification rules in the 2021edition provide equivalent safety to procedure specification rules in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		Rules for welding procedure qualification are specified in Part QW, Article II in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for brazing procedure qualification are specified in Part QB, Article XII in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for plastic fusing procedure qualification are only specified in Part QF, Article XXII in the 2021 edition of Section IX of the ASME BPVC.	Procedure specification rules for fusing are not specified in the 2007 edition.
5.3.4	Rules in Section IX for Procedure Qualification Record (PQR)	The Procedure Qualification Record (PQR) documents what occurred during the production of a procedure qualification test coupon and the results of testing that coupon. As a minimum, the record must document the essential variables for each process used to produce the test coupon, the ranges of variables qualified, and the results of the required testing and nondestructive examinations. The organization must certify a PQR by a signature or other means as described in the organization's Quality Control System and must make the PQR accessible to the Authorized Inspector. Rules that govern PQR are specified in Paragraph QW-200.2 for welding and QB-200.2 for brazing in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules that govern PQR for plastic fusing are specified in Paragraph QF-201.5 for in the 2021 edition of Section IX of the ASME BPVC.	Procedure qualification record rules in the 2021 edition provide equivalent safety to procedure qualification record rules in the 2007 edition.
5.3.5	Rules in Section IX for Performance Qualification	The purpose of qualifying the person who will use a joining process is to demonstrate that person's ability to produce a sound joint when using a Procedure Specification. Rules for welding performance qualification are specified in Part QW, Article III in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for brazing performance qualification are specified in Part QB, Article XIII in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for plastic fusing performance qualification are only specified in Part QF, Article XXIII in the 2021 edition of Section IX of the ASME BPVC.	Performance qualification rules in the 2021 edition provide equivalent safety to performance qualification rules in the 2007 edition. Performance qualification rules for fusing are not specified in the 2007 edition.
5.3.6	Rules in Section IX for Performance Qualification Record	The performance qualification record documents what occurred during the production of a test coupon by a person using one or more joining processes following an organization's PS. As a minimum, the record shall document: *(a)* the essential variables for each process used to produce the test coupon	Performance qualification record rules in the 2021 edition provide equivalent safety to performance

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		(b) the ranges of variables qualified as required by the applicable part (see QW-301.4, QB-301.4, and QF-301.4) *(c)* the results of the required testing and nondestructive examinations *(d)* the identification of the procedure specification(s) followed during the test Rules for Welder/Welding Operator Performance Qualification (WPQ) are specified in Paragraph QW-301.4 in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for Brazer or Brazing Operator Performance Qualification (BPQ) are specified in Paragraph QB-301.4 in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for Fusing Operator Performance Qualification Record (FPQ) are specified in Paragraph QF-301.4 in the 2021 edition of Section IX of the ASME BPVC.	qualification record rules in the 2007 edition. Performance qualification record rules for fusing are not specified in the 2007 edition.
5.3.7	Rules in Section IX Welding, Brazing, and Fusing Data	Welding, brazing, and fusing data articles include the variables grouped into categories such as joints, base materials and filler materials, positions, preheat and postweld heat treatment, gas, electrical characteristics, and technique. These variables are referenced from other articles as they apply to each process. Welding data include essential, supplementary essential, or nonessential variables. Brazing data include essential and nonessential variables. Fusing data include the fusing variables grouped as joints, pipe material, position, thermal conditions, equipment, and technique. Rules for welding data are specified in Part QW, Article IV in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for brazing data are specified in Part QB, Article XIV in the 2007 and 2021 editions of Section IX of the ASME BPVC. Rules for fusing data are only specified in Part QF, Article XXIV in the 2021 edition of Section IX of the ASME BPVC.	Welding and brazing, data rules in the 2021 edition provide equivalent safety to welding and brazing, data rules in the 2007 edition. Fusing data rules are not specified in the 2007 edition.
5.4.1.3	Preheating Requirements	Requirements for preheating of welds are provided in Paragraph 6.4.1 in the in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. Guidelines for preheating are provided in Table 6.7 – Minimum Preheat Temperatures for Welding for the materials listed by P-Numbers in Section IX. It is cautioned that the preheating parameters shown in this table do not necessarily ensure satisfactory completion of the welded joint, and requirements for individual materials for the P-Number listing may have preheating requirements that are more restrictive.	Preheating rules in the 2021 edition provide equivalent safety to preheating rules in the 2007 edition.
5.4.2.3	Postweld Heat Treatment Requirements	Requirements for postweld heat treatment are provided in Paragraph 6.4.2 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. In the 2007 edition, minimum postweld heat treatment holding temperatures are specified in Tables 6.8 through 6.15 for P-Numbers 1, 3, 4, 5A, 5B, 5C, 6, 7, 8, 9A, 9B, 10A, 10B, 10E, 10F, 10G, 10H, 10I, and 10K materials. Table 6.16 provides alternative postweld heat treatment requirement for carbon and low alloy steels. In the	Postweld heat treatment rules in the 2021 edition provide equivalent safety to postweld heat treatment

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		2021 edition, minimum postweld heat treatment holding temperatures are specified in Tables 6.8 through 6.15 for P-Numbers 1, 3, 4, 5A, 5B, 5C, 15E, 6, 7, 8, 9A, 9B, 10A, 10B, 10C, 10E, 10F, 10G, 10H, 10I, 10K, and 45 materials. Table 6.16 provides alternative postweld heat treatment requirement for carbon and low alloy steels. Requirements for postweld heat treatment provided in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC cover materials from different groups of P-Numbers as described in Sect. 5.3.1 of this report.	rules in the 2007 edition.
5.5	Cold Stretching	The 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC do not include cold stretching requirements.	An equivalent safety evaluation of cold stretching requirements in the 2007 and 2021 editions is not possible.
5.6.3	Quality Control System	Quality control system requirements are provided in Part 2 – Responsibilities and Duties, Paragraph 2.3.6 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. Both paragraphs state that the Manufacturer shall have and maintain a Quality Control System in accordance with Annex 2-E – Quality Control System. According to requirements provided in Annex 2-E, the Manufacturer shall have and maintain a quality control system that establishes that all Code requirements, including material, design, fabrication, examination (by the Manufacturer), and inspection of vessels and vessel parts (by the Inspector), will be met. Guidelines for the features to be included in the written description of the quality control system are described in Annex 2-E, Paragraphs 2-E.3 through 2-E.16 in the 2021 edition of Section VIII, Division 2 of the ASME BPVC. Guidelines in Paragraphs 2-E.10 – Nondestructive Examination states that the quality control system should include provisions for identifying nondestructive examination procedures the Manufacturer or Assembler will apply to conform to the requirements of this Division. Rules specified in Annex 2-G – Obtaining and Using Certification Mark Stamps in the 2021 edition of Section VIII, Division 2 of the ASME BPVC state that any Manufacturer holding or applying for a Certificate of Authorization shall demonstrate a quality control system that meets the requirements of ASME CA-1 and Annex 2-E. Publication ASME CA-1 [2] specifies requirements for accreditation and certification of organizations supplying products or services that are intended to conform to the requirements of ASME standards listed in Table 1 – ASME Certification Programs. Table 1 in ASME CA-1	Quality control system requirements in the 2021 edition provide equivalent safety to quality control system requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		assigns the ASME Certification Designator “U2 – Pressure Vessel, Division 2” to Section VIII, Division 2 of the ASME BPVC. Publication ASME CA-1 was initially issued in 2013.	
6.2.3	General NDE Requirements	Inspection and examination requirements are provided in Part 7 – Inspection and Examination Requirements in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. Rules in Paragraph 7.4 – Nondestructive Examination Requirements for examination of welded joints. Part 7, Table 7.1 – Examination Groups for Pressure Vessels defines the Examination Groups assigned to welded joints based on the manufacturing complexity of the material group, the maximum thickness, the welding process, and the selected joint efficiency. According to requirements provided in Table 7.3 – Selection of Nondestructive Testing Method for Full Penetration Joints in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC, full penetration joints with a thickness less than 1/2 in. must be examined using radiographic examination, but full penetration joints with a thickness equal to or greater than 1/2 in. may be examined using either radiographic or ultrasonic examination. Paragraph 7.3 – Qualification of Nondestructive Examination Personnel in the 2021 edition of Section VIII, Division 2 of the ASME BPVC states that personnel performing nondestructive examinations in accordance with: Paragraph 7.5.3 – Radiographic Examination (RT) Paragraph 7.5.4 – Ultrasonic Examination (UT) Paragraph 7.5.5 – Ultrasonic Examination Used In lieu of Radiographic Examination Paragraph 7.5.6 – Magnetic Particle Examination (MT) Paragraph 7.5.7 – Liquid Penetrant Examination (PT) Paragraph 7.5.8 – Eddy Current Surface Examination Procedure Requirements (ET) shall be qualified and certified in accordance with the requirements of Section V, Article 1 – General Requirements, T-120*(e)*, T-120*(f),* T-120*(g)*, T-120*(i)*, T-120*(j)*, or T-120*(k)*, as applicable. Differences in requirements provided in Section V, Article 1 – General Requirements, Paragraph T-120 in the 2007 and 2021 editions concerning qualification of NDE personnel are discussed in Sect. 6.3.1 of this report.	General NDE requirements in the 2021 edition provide equivalent safety to general NDE requirements in the 2007 edition.
6.2.3.1	Radiographic Examination Requirements	Rules for radiographic examination of joints in pressure vessels fabricated by welding in accordance with requirements specified in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC are provided in Part 7 – Inspection and Examination Requirements, Paragraph 7.5.3 – Radiographic Examination.	Radiographic examination requirements in the 2021 edition provide equivalent safety to

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		Paragraph 7.5.3.1 – Examination Method in 2021 edition of Section VIII, Division 2 of the ASME BPVC states that all welded joints to be radiographed shall be examined and documented in accordance with Section V, Article 2 except as specified below. *(a)* A complete set of radiographs and records, as described in Section V, Article 2, T-291 and T-292, for each vessel or vessel part shall be retained by the Manufacturer in accordance with 2.3.5. *(b)* Personnel performing and evaluating radiographic examinations required by this Division shall be qualified and certified in accordance with 7.3. *(c)* Evaluation of radiographs shall only be performed by RT Level II or III personnel. *(d)* Demonstration of density and Image Quality Indicator (IQI) image requirements on production or technique radiographs shall be considered satisfactory evidence of compliance with Section V, Article 2. *(e)* Final acceptance of radiographs shall be based on the ability to see the prescribed hole (IQI) image and the specified hole or the designated wire of a wire IQI. *(f)* Ultrasonic examination of SAW welds in 2-1/4 Cr–1Mo–1/4 V vessels in accordance with 7.5.4.1*(e)* is required. Differences in qualification and certification requirements for personnel performing and evaluating radiographic examinations between the 2007 and 2021 editions of Section VIII, Division 2 are explained in Sect. 6.2.3.1 of this report.	radiographic examination requirements in the 2007 edition.
6.2.3.2	Ultrasonic Examination Requirements	Rules for ultrasonic examination of joints in pressure vessels fabricated by welding in accordance with requirements specified in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC are provided in Part 7 – Inspection and Examination Requirements, Paragraph 7.5.4 – Ultrasonic Examination. Rules for ultrasonic examination of joints in pressure vessels fabricated by welding in accordance with requirements specified in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC are provided in Part 7 – Inspection and Examination Requirements, Paragraph 7.5.4 – Ultrasonic Examination. According to these rules in the 2021 edition, all welded joints subjected to ultrasonic examination must be examined in accordance with requirements specified in Section V, Article 4 except as specified in Paragraph 7.5.4.1*(a)* through *(e)*. *(a)* A complete set of records, as described in Section V, Article 4, T-491 and T-492, for each vessel or vessel part shall be retained by the Manufacturer in accordance with 2-C.3. In addition, a record of repaired areas shall be noted as well as the results of the reexamination of the repaired areas. The Manufacturer shall also maintain a record from uncorrected areas	Ultrasonic examination requirements in the 2021 edition provide equivalent safety to ultrasonic examination requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		having responses that exceed 50% of the reference level. This record shall locate each area, the response level, the dimensions, the depth below the surface, and the classification. *(b)* Personnel performing and evaluating ultrasonic examinations required by this Division shall be qualified and certified in accordance with 7.3. *(c)* Flaw evaluations shall only be performed by UT Level II or III personnel. *(d)* Ultrasonic examination shall be performed in accordance with a written procedure certified by the Manufacturer to be in accordance with the requirements of Section V, Article 1, T-150. *(e)* SAW welds in 2-1/4Cr–1Mo–1/4V vessels require ultrasonic examination using specialized techniques beyond those required by this Division (see 2.2.3.2). Annex A of API Recommended Practice 934-A may be used as a guide in the selection of the examination specifics. Rules specified in Part 7, Paragraph 7.5.5 Ultrasonic Examination Used in Lieu of Radiographic Examination in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC, when used in lieu of the radiographic examination requirements of 7.5.3, automated or semi-automated ultrasonic shall be performed in accordance with a written procedure conforming to the requirements of Section V, Article 4, Mandatory Appendix VIII – Ultrasonic Examination Requirements for Fracture-Mechanics-Based Acceptance Criteria or Mandatory Appendix XI – Full Matrix Capture, as applicable, and the additional requirements specified in Paragraph 7.5.5.1*(a)* through *(f)*. Differences in qualification and certification requirements for personnel performing and evaluating ultrasonic examinations between the 2007 and 2021 editions of Section VIII, Division 2 are explained in Sect. 6.2.3.2 of this report.	
6.2.3.3	Magnetic Particle Examination Requirements	Rules for magnetic particle examination of welded joints in pressure vessels fabricated by welding in accordance with requirements specified in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC are provided in Part 7 – Inspection and Examination Requirements, Paragraph 7.5.6 – Magnetic Particle Examination (MT). According to these rules in the 2021 edition, all magnetic particle examinations shall be performed and documented in accordance with Section V, Article 7 except as specified in Paragraph 7.5.6.1 below: *(a)* A complete set of records, as described in Section V, Article 7, T-790, for each vessel or vessel part shall be retained by the Manufacturer until the Manufacturer's Data Report has been signed by the Inspector.	Magnetic particle examination requirements in the 2021 edition provide equivalent safety to magnetic particle examination requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		(b) Personnel performing and evaluating magnetic particle examinations required by this Division shall be qualified and certified in accordance with 7.3. Evaluation of magnetic particle examination shall only be performed by MT Level II or III personnel. *(c)* Magnetic particle examination shall be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of Section V, Article 1, T-150. *(d)* Indications will be revealed by retention of magnetic particles. All such indications are not necessarily imperfections, however, since excessive surface roughness, magnetic permeability variations (such as the edge of heat-affected zones), etc., may produce similar indications. An indication of an imperfection may be larger than the imperfection that causes it; however, the size of the indication is the basis for acceptance evaluation. Only indications which have any dimension greater than 1.5 mm (1/16 in.) shall be considered relevant. *(1)* A linear indication is one having a length greater than three times the width. *(2)* A rounded indication is one of circular or elliptical shape with a length equal to or less than three times its width. *(3)* Any questionable or doubtful indications shall be reexamined to determine whether or not they are relevant. Differences in qualification and certification requirements for personnel performing and evaluating magnetic particle examinations between the 2007 and 2021 editions of Section VIII, Division 2 are explained in Sect. 6.2.3.3 of this report.	
6.2.3.4	Liquid Penetrant Examination Requirements	Rules for liquid penetrant examination of welded joints in pressure vessels fabricated by welding in accordance with requirements specified in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC are provided in Part 7 – Inspection and Examination Requirements, Paragraph 7.5.7 – Liquid Penetrant Examination (PT). According to these rules in the 2021 edition, all liquid penetrant examinations shall be performed and documented in accordance with Section V, Article 6 except as specified in Paragraph 7.5.7.1 below: *(a)* A complete set of records, as described in Section V, Article 6, T-691 and T-692, for each vessel or vessel part shall be retained by the Manufacturer until the Manufacturer's Data Report has been signed by the Inspector. *(b)* Personnel performing and evaluating liquid penetrant examinations required by this Division shall be qualified and certified in accordance with 7.3. Evaluation of liquid penetrant examination shall only be performed by PT Level II or III personnel.	Liquid penetrant examination requirements in the 2021 edition provide equivalent safety to liquid penetrant examination requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		(c) Liquid penetrant examination shall be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of Section V, Article 1, T-150. *(d)* An indication of an imperfection may be larger than the imperfection that causes it; however, the size of the indication is the basis for acceptance evaluation. Only indications with major dimensions greater than 1.5 mm (1/16 in.) shall be considered relevant. *(1)* A linear indication is one having a length greater than three times the width. *(2)* A rounded indication is one of circular or elliptical shape with a length equal to or less than three times its width. *(3)* Any questionable or doubtful indications shall be reexamined to determine whether or not they are relevant. Differences in qualification and certification requirements for personnel performing and evaluating magnetic particle examinations between the 2007 and 2021 editions of Section VIII, Division 2 are explained in Sect. 6.2.3.4 of this report.	
6.2.3.5	Eddy Current Examination Requirements	Rules for eddy current surface examination procedure requirements are specified in Part 7 – Inspection and Examination Requirements, Paragraph 7.5.8 – Eddy Current Surface Examination Procedure Requirements (ET) in the 2007 and 2021 editions of Section VIII, Section VIII, Division 2 of the ASME BPVC. According to these rules in the 2021 edition, all eddy current examinations shall be performed and documented as described in Paragraph 7.5.7.1 below: *(a)* A complete set of records for each vessel or vessel part shall be retained by the Manufacturer until the Manufacturer's Data Report has been signed by the Inspector. *(b)* Personnel performing and evaluating eddy current examinations required by this Division shall be qualified and certified in accordance with 7.3. Evaluation of eddy current examination shall only be performed by ET Level II or III personnel. *(c)* Eddy current examinations shall be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of Section V, Article 1, T-150. Differences in qualification and certification requirements for personnel performing and evaluating magnetic particle examinations between the 2007 and 2021 editions of Section VIII, Division 2 are explained in Sect. 6.2.3.5 of this report.	Eddy current examination requirements in the 2021 edition provide equivalent safety to eddy current examination requirements in the 2007 edition.
6.2.3.6	Visual Examination Requirements	Rules for visual examination of joints in pressure vessels fabricated by welding in accordance with requirements specified in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC are specified in Part 7 – Inspection and Examination Requirements, Paragraph 7.5.2 –	Visual examination requirements in the 2021 edition provide

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		Visual Examination. According to rules in the Paragraph 7.5.2.1 – Examination Method in the 2021 edition, all accessible welds for pressure-retaining parts shall be visually examined. Differences in qualification and certification requirements for personnel performing and evaluating visual examinations between the 2007 and 2021 editions of Section VIII, Division 2 are explained in Sect. 6.2.3.5 of this report.	equivalent safety to visual examination requirements in the 2007 edition.
6.2.4.3	NDE Acceptance Standards	As Tables 6.1 through 6.5 of this report show, acceptance standards provided in Section VIII, Division 2 for radiographic, ultrasonic, magnetic particle, liquid penetrant, and eddy current examinations are comparable. However, compared to the 2007 edition, acceptance standards for radiographic examinations provided in Paragraph 7.5.3.2 in the 2021 edition of Section VIII, Division 2 were expanded to include groups of linear indications and more well-defined shape characteristics of rounded indications.	NDE acceptance standards in the 2021 edition provide equivalent safety to NDE acceptance standard in the 2007 edition.
6.2.5	Summary of Qualification and Certification Requirements for NDE Personnel	As discussed in Sect. 6.1 of this report, the Manufacturer is responsible for training, qualifying, and certifying of NDE personnel that perform NDE methods and evaluate NDE results. Requirements for qualification and certification for NDE personnel that are provided in Section I; Section VIII, Division 1; and Section VIII, Division 2 of the ASME BPVC are discussed in Sects. 6.2.1, 6.2.2, and 6.2.3 of this report, respectively. Table 6.6 is a crosswalk that maps paragraphs in Section I; Section VIII, Division 1; and Section VIII, Division 2 that provide qualification and certification requirements for NDE personnel to reference sections in this report where these qualification and certification requirements are examined and explained.	Certification requirement for NDE personnel in the 2021 edition provide equivalent safety to certification requirement for NDE personnel in the 2007 edition.
6.3.1	General NDE Requirements	Article 1 – General Requirements in the 2007 and 2021 editions of Section V of the ASME BPVC provide general requirements and methods for NDE which are Code requirements to the extent they are specifically referenced and required by a Construction Code or referencing documents. These NDE methods are used to detect surface and internal imperfections in materials, welds, fabricated parts, and components. Rules for certification of nondestructive examination personnel are specified in Paragraphs T-120*(e)* and *(f)* in the 2021 edition of Section V of the ASME BPVC. These rules state: *(e) For those documents that directly reference this Article for the qualification of NDE personnel, the qualification shall be in accordance with their employer's written practice which shall be in accordance with one of the following documents:* *(1) SNT-TC-1A (2016 Edition), Personnel Qualification and Certification in Nondestructive Testing, as amended by Mandatory Appendix III; or*	General NDE requirements in the 2021 edition provide equivalent safety to general NDE requirements in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		(2) ANSI/ASNT CP-189 (2016 Edition), ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel, as amended by Mandatory Appendix IV *(f) National or international central certification programs, such as the ASNT Central Certification Program (ACCP) or ISO 9712:2012-based programs, may be alternatively used to fulfill the training, experience, and examination requirements of the documents listed in (e) as specified in the employer's written practice.* By comparison, Paragraph T-120*(e)* in the 2007 edition of Section V of the ASME BPVC specified the 2001 editions of SNT-TC-1A and ANSI/ASNT CP-189, and Paragraph T-120*(f)* in the 2007 edition of Section V of the ASME BPVC added ISO 9712:2012-based programs as an example of a National or international central certification program. Addition rules for certification of NDE personnel are provided in Paragraphs T-120*(g)* and *(h)* in the 2021 edition of Section V of the ASME BPVC. These rules state: *(g) In addition to the requirements described in (e) or (f) above, if the techniques of computed radiography (CR), digital radiography (DR), phased-array ultrasonic (PAUT), ultrasonic time-of-flight diffraction (TOFD), or ultrasonic full matrix capture (FMC) are to be used, the training, experience, and examination requirements found in Article 1, Mandatory Appendix II shall also be included in the employer's written practice for each technique as applicable.* *(h) Alternatively, performance-based qualification programs, in accordance with ASME ANDE-1-2015, ASME Nondestructive Examination and Quality Control Central Qualification and Certification Program, may be used for training, experience, examination, and certification activities as specified in the written practice.* The alternative rules for performance-based qualification programs permitted in Paragraphs T-120*(h)* in the 2021 edition of Section V are not included in the 2007 edition of Section V of the ASME BPVC.	
6.3.2	Radiographic Examination Requirements in Section V	Article 2 – Radiographic Examination in the 2007 and 2021 editions of Section V of the ASME BPVC provides requirements for radiographic examination of materials including castings and welds. The extent of radiographic examinations is as specified by the referencing Construction Code. Product-specific, technique-specific, and application-specific requirements are also provided in mandatory appendices provided in Section V, Article 2.	Radiographic examination requirements in Section V in the 2021 edition provide equivalent or greater safety to radiographic

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		Paragraph III-210 in Mandatory Appendix III in the 2007 and 2021 editions of Section V of the ASME BPVC states: *Digital image acquisition, display, and storage can be applied to radiography and radioscopy. Once the analog image is converted to digital format, the data can be displayed, processed, quantified, stored, retrieved, and converted back to the original analog format, for example, film or video presentation.* This requirement in Mandatory Appendix III only applies to digital image acquisition, display, and storage for radiography and radioscopy and not to digital radiography (DR) techniques as an alternative to film radiography. Rules in Paragraph IX-210 – Scope in Mandatory Appendix IX – Radiography Using Digital Detector Systems in the 2021 edition of Section V of the ASME BPVC specify requirements for the use of direct radiography (DR) techniques using digital detector systems (DDSs), where the image is transmitted directly from the detector rather than using an intermediate process for conversion of an analog image to a digital format. Mandatory Appendix IX also addresses applications in which the radiation detector, the source of the radiation, and the object being radiographed may or may not be in motion during exposure. Section V, Article 2 provisions apply unless modified by Mandatory Appendix IX. Radiography using digital detector systems as specified in Mandatory Appendix IX in the 2021 edition of Section V of the ASME BPVC is permitted as an alternative to digital image acquisition as provided in Mandatory Appendix III – Digital Image Acquisition, Display, and Storage for Radiography and Radioscopy in the 2007 and 2021 edition of Section V of the ASME BPVC. As noted above, the 2007 edition of Section V of the ASME BPVC does not include Mandatory Appendix IX – Application of Digital Radiography and Mandatory Appendix IX – Supplement A. Computed radiography (CR) and digital radiography (DR) are commonly used terms for digital radiographic detectors. Computed radiography uses a photostimulable storage phosphor that stores the latent image with subsequent processing using a stimulating laser beam and can be easily adapted to a cassette-based system analogous to that used in screen-film radiography. Historically, DR has been used to describe a digital X-ray imaging system that reads the transmitted X-ray signal immediately after exposure with the detector in place. Use of CR or DR provides equivalent or greater safety compared to use of film radiography and digital image acquisition provided NDE personnel are qualified and certified in the use of these methods.	examination requirements in Section V in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		Rules for radiographic examination of welded joints are specified in Paragraph UW-51 – Radiographic Examination of Welded Joints in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. These rules state that all welds that require radiographic examination must be examined in accordance with rules specified in Article 2 – Radiographic Examination, Section V of the ASME BPVC, except as specified Paragraphs UW-51*(a)(1)* through *(a)(4)*.	
6.3.3	Ultrasonic Examination Requirements in Section V	Paragraph T-410 – Scope in Article 4 – Ultrasonic Examination Methods for Welds in the 2007 and 2021 editions of Section V of the ASME BPVC provides or references requirements for weld examinations. These requirements are used in selecting and developing ultrasonic examination procedures when examination to any part of this Article is a requirement of a referencing Code Section. These procedures are to be used for ultrasonic examinations and for dimensioning of indications for comparison with acceptance standards. Paragraph T-421 – Written Procedure Requirements states that ultrasonic examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table T-421 – Requirements of an Ultrasonic Examination Procedure or the Mandatory Appendices applicable to the technique in use. Product-specific, technique-specific, and application-specific requirements are also provided in the mandatory appendices in Section V, Article 4. Requirements provided in Article 4, Paragraph T-420 – General in the 2021 editions of Section V of the ASME BPVC were expanded from the 2007 edition to state: *The requirements of this Article shall be used together with Article 1, General Requirements. Refer to:* *(a) special provisions for coarse grain materials and welds in T-451* (provided in 2007 and 2021 editions) *(b) special provisions for computerized imaging techniques in T-452* (provided in 2007 and 2021 editions) *(c) Mandatory Appendix III for Time of Flight Diffraction (TOFD) techniques* (provided in 2021 edition) *(d) Mandatory Appendix IV for phased array manual rastering techniques* (provided in 2021 edition) *(e) Mandatory Appendix V for phased array E-scan and S-scan linear scanning examination techniques* (provided in 2021 edition) *(f) Mandatory Appendix XI for full matrix capture (FMC) techniques* (provided in 2021 edition)	Ultrasonic examination requirements in Section V in the 2021 edition provide equivalent safety to ultrasonic examination requirements in Section V in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		Paragraph 12-1*(b)* in Mandatory Appendix 12 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC states that Section V, Article 4 shall be applied for detail requirements in methods and procedures, unless otherwise specified in this Appendix.	
6.3.4	Magnetic Particle Examination Requirements in Section V	Article 7 – Magnetic Particle Examination, Paragraph T-710 – Scope in the 2007 and 2021 editions of Section V of the ASME BPVC states that the magnetic particle examination techniques described in this Article must be used together with Article 1 – General Requirements when specified by the referencing Construction Code. Requirements in T-721 – Written Procedure Requirements states that magnetic particle examination shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table T-721 – Requirements of a Magnetic Particle Examination Procedure. Additional magnetic particle examination requirements are provided in the 2021 editions of Article 7, Section V of the ASME BPVC in the mandatory appendices. Paragraph UG-103 – Nondestructive Testing in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC states that where magnetic particle examination is prescribed in this Division it shall be done in accordance with Mandatory Appendix 6 – Methods for Magnetic Particle Examination (MT). The rules for magnetic particle examination specified in Mandatory Appendix 6 state that Section V, Article 7 shall be applied for the detail requirements in methods and procedures, and the additional requirements specified within this Appendix.	Magnetic particle examination requirements in Section V in the 2021 edition provide equivalent safety to magnetic particle examination requirements in Section V in the 2007 edition.
6.3.5	Liquid Penetrant Examination Requirements in Section	Article 6 – Liquid Penetrant Examination, Paragraph T-610 – Scope in the 2007 and 2021 editions of Section V of the ASME BPVC states that when this Article is specified by a referencing Code Section, the liquid penetrant method described in Article 6 shall be used together with Article 1 – General Requirements. Requirements in Paragraph T-621 – Written Procedure Requirements states that liquid penetrant examination shall be performed in accordance with a written procedure which shall as a minimum, contain the requirements listed in Table T-621.1 – Requirements of a Liquid Penetrant Examination Procedure. Additional liquid penetrant examination requirements are provided in the mandatory appendices. Paragraph UG-103 – Nondestructive Testing in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC states that where liquid penetrant examination is prescribed in this Division it shall be done in accordance with where liquid penetrant examination is prescribed in this Division it shall be done in accordance with Appendix 8 – Methods for Liquid Penetrant Examination (PT). The rules for liquid penetrant examination specified in Mandatory Appendix 8 state that Section V, Article 6 shall be applied for the detail requirements in methods and procedures, and the additional requirements specified within this Appendix.	Liquid penetrant examination requirements in Section V in the 2021 edition provide equivalent safety to liquid penetrant examination requirements in Section V in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
6.3.6	Eddy Current Examination Requirements in Section V	Article 8 – Eddy Current Examination in the 2007 and 2021 editions of Section V of the ASME BPVC states that the eddy current examination method and techniques described in this Article shall be used when specified by the referencing Code Section. Additional eddy current examination requirements are provided in the 2021 editions of Article 8, Section V of the ASME BPVC in the mandatory appendices. Requirements for eddy current examinations are not provided in either the 2007 or the 2021 edition of Section VIII, Division 1 of the ASME BPVC.	Eddy current examination requirements in Section V in the 2021 edition provide equivalent safety to eddy current examination requirements in Section V in the 2007 edition.
6.3.7	Visual Examination Requirements in Section V	Article 9 – Visual Examination, Paragraph T-910 – Scope in the 2007 and 2021 editions of Section V of the ASME BPVC states that methods and requirements for visual examination in this Article are applicable together with requirements of Article 1 – General Requirements when specified by a referencing Construction Code. Specific visual examination procedures required for every type of examination are not included in this Article because there are many applications where visual examinations are required. Requirements in T-921 – Written Procedure Requirements states that visual examinations shall be performed in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table T-921 – Requirements of a Visual Examination Procedure.	Visual examination requirements in Section V in the 2021 edition provide equivalent or greater safety to visual examination requirements in Section V in the 2007 edition.
7.1.3.1	Basis for Hydrostatic Pressure Testing Limits	Hydrostatic pressure testing requirements for pressure vessels that are designed and fabricated in accordance with rules specified in Section VIII, Division 2 are provided in Paragraph 8.2.1 – Test Pressure and Paragraph 4.1.6.2 – Test Condition in the 2007 and 2021 editions of the ASME BPVC. These hydrostatic pressure testing requirements are explained in detail in Sect. 7.1.3.1 of this report. Equations for establishing the minimum hydrostatic test pressure are provided in Paragraph 8.2.1 and equations for establishing the maximum hydrostatic test pressure are provided in Paragraph 4.1.6.2. The minimum and maximum hydrostatic test pressure, P_T, produced by solving these equations are compared below. 2021 – minimum hydrostatic test pressure – 1.25 MAWP for Class 1 and Class 2 2021 – maximum general membrane stress limit – 0.95 P_m for Class 1 and Class 2 2007 – minimum hydrostatic test pressure – greater of 1.43 MAWP or 1.25 MAWP $\left(\frac{S_T}{S}\right)$	Hydrostatic pressure testing limits in the 2021 edition provide equivalent safety to hydrostatic pressure testing limits in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		2007 – maximum general membrane stress limit – 0.95 P_m A pressure vessel that is hydrostatically pressure tested to 1.43 MAWP has a general membrane stress that is less than or equal to 0.95 times the yield strength, S_y, of the material. Whereas an identical pressure vessel that is hydrostatically pressure tested to 1.25 MAWP has a general membrane stress that is less than or equal to 0.83 times the yield strength, S_y, of the material. For a safety viewpoint, these two pressure vessels are equally safe for the following reasons. a. A pressure test is performed after fabrication is completed primarily to verify the leak tight integrity of the pressure vessel, but also to identify gross deformations or anomalies that may indicate design errors, material deficiencies, or weld defects. Pressure test limits are established to maintain primary membrane and bending stresses within the elastic range, so the pressure vessel does not permanently deform. Pressure tests are not intended to verify the pressure-resisting (burst) capacity of a pressure vessel. b. The primary membrane stress, P_m, remains at or below the plastic collapse stress limit which corresponds to a primary membrane stress equals 1.0 times the yield strength, S_y, of the material and which ASME considers safe. c. The maximum and minimum hydrostatic test pressures are equal when MAWP is based on an allowable primary membrane stress, P_m, equal to $2/3\, S_y$ (i.e., $0.95 \times 1.5\text{MAWP} = 1.43\text{ MAWP}$). Controlling the hydrostatic test pressure to a pressure of at least 1.43 MAWP but not more than 1.43 MAWP could be problematic. d. A pressure test (either hydrostatic or pneumatic) is conducted so the Authorized Inspector can authorize application of the Certification Mark (Code stamp) based on verification of leak tight integrity and confirm that the pressure vessel does not exhibit gross deformations or anomalies that may indicate design errors, material deficiencies, or weld defects. e. Part 9 in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC state that when a pressure vessel can be exposed to fire or other unexpected sources of external heat, the pressure relief device(s) must be capable of preventing the pressure from rising more than 21% above the MAWP. (i.e., 1.21 MAWP). This overpressure protection limit ensures that the primary membrane stress, P_m, does not exceed 0.81 S_y (i.e., $1.21/1.50$). A minimum hydrostatic test pressure equal to 1.25 MAWP ensures that the pressure vessel will never experience a maximum overpressure while in service that is greater than the hydrostatic test pressure. (i.e., $1.25\text{ MAWP} > 1.21\text{ MAWP}$). Rules specified in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC do not specify a minimum or maximum hydrostatic test pressure duration.	

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
7.1.3.2	Basis for Pneumatic Pressure Testing Limits	Pneumatic pressure testing requirements for pressure vessels that are designed and fabricated in accordance with rules specified in Section VIII, Division 2 are provided in Paragraph 8.3.1 – Test Pressure in the 2007 edition, Paragraph 8.2.1 – Test Pressure in the 2021 edition, and Paragraph 4.1.6.2 – Test Condition in the 2007 and 2021 editions of the ASME BPVC. These pneumatic pressure testing requirements are explained in detail in Sect. 7.1.3.2 of this report. Equations for establishing the minimum pneumatic test pressure are provided in Paragraph 8.3.1 in the 2007 edition and Paragraph 8.2.1 in the 2021and equation for establishing the maximum pneumatic test pressure are provided in Paragraph 4.1.6.2 in the 2007 and 2021 editions. The minimum and maximum pneumatic test pressure, P_T, produced by solving these equations are compared below. 2021 – minimum hydrostatic test pressure – 1.15 MAWP for Class 1 and Class 2 2021 – maximum general membrane stress limit – 0.80 P_m for Class 1 and Class 2 2007 – minimum hydrostatic test pressure – $1.15 \text{ MAWP} \left(\frac{S_T}{S}\right)$ 2007 – maximum general membrane stress limit – 0.80 P_m These limits means that when a pressure vessel is subjected to a text pressure equal to 1.15 MAWP, the primary membrane stress, P_m, is equal to $0.76S_y$, or less. Pressure vessels that are designed and fabricated in accordance with rules specified in the 2021 edition of Section VIII, Division 2 of the ASME BPVC and subjected to a pneumatic test pressure equal to 1.15 MAWP are equivalent in safety to pressure vessels that are designed and fabricated in accordance with rules specified in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and subjected to a pneumatic test pressure equal to 1.15 MAWP because: a. A pressure test is performed after fabrication is completed primarily to verify the leak tight integrity of the pressure vessel, but also to identify gross deformations or anomalies that may indicate design errors, material deficiencies, or weld defects. Pressure test limits are established to maintain primary membrane and bending stresses within the elastic range, so the pressure vessel does not permanently deform. Pressure tests are not intended to verify the pressure-resisting (burst) capacity of a pressure vessel. b. The primary membrane stress, P_m, remains at or below the plastic collapse stress limit which corresponds to a primary membrane stress equals 1.0 times the yield strength, S_y, of the material and which ASME considers safe. c. A pressure test (either hydrostatic or pneumatic) is conducted so the Authorized Inspector can authorize application of the Certification Mark (Code stamp) based on verification of leak	Pneumatic pressure testing limits in the 2021 edition provide equivalent safety to pneumatic pressure testing limits in the 2007 edition.

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		tight integrity and confirm that the pressure vessel does not exhibit gross deformations or anomalies that may indicate design errors, material deficiencies, or weld defects. Rules specified in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC do not specify a minimum or maximum pneumatic test pressure duration.	
7.2	Alternative Pressure Testing	Alternative pressure testing rules are provided in Part 8 – Pressure Testing Requirements in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC. According to alternative pressure testing requirements specified in Paragraph 8.4 in the 2007 edition and Paragraph 8.3 in the 2021 edition, in cases where it is desirable to pressure test a pressure vessel partially filled with liquid, the requirements of Paragraph 8.3 in the 2007 edition or Paragraph 8.2 in the 2021 edition must be met, except the pneumatic pressure applied above the liquid level must at no point result in a total pressure that causes the general membrane stress to exceed 80% of the specified minimum yield strength of the material at test temperature. Requirements for leak tightness testing are specified in Paragraph 8.4.2 in the 2007 edition and Paragraph 8.3.2 in the 2021 edition as follows. a) Leak tightness tests include a variety of methods of sufficient sensitivity to allow for the detection of leaks in pressure elements, including, but not limited to the use of direct pressure and vacuum bubble test methods, and various gas detection tests. b) The selection of a leak tightness test to be employed should be based on the suitability of the test for the particular pressure element being tested. c) The metal temperature for leak tightness tests must be in accordance with Paragraph 8.3.4.a. Additionally, the temperature must be maintained within the specified range for the test equipment being used. d) Leak tightness tests must be performed in accordance with Article 10 of Section V.	Alternative pressure testing rules in the 2021 edition provide equivalent safety to alternative pressure testing rules in the 2007 edition
7.3.3	Proof Testing	Rules for proof testing are not provided in the 2007 and 2021 editions of Section VIII, Division 2 of the ASME BPVC.	An equivalent safety evaluation of proof testing requirements in the 2007 and 2021 editions is not possible.
8.3	Overpressure Protection by Pressure Relief Device	All Section VIII, Division 2 pressure relief device requirements have been transferred from Part 9 – Pressure Vessel Overpressure Protection to Section XIII – Rules for Overpressure Protection and the remaining Division 2 overpressure protection requirements have been restructured within Part 9. Annex 9-B – Guide to the Relocation of Overpressure Protection Requirements provides a complete cross-reference list in Table 9-B.1-1 – Cross-Reference List.	Due to restructuring of paragraphs in the 2021 edition and transferring to Section XIII, a comprehensive equivalent safety

Reference section of this report	Rule or Requirement	Equivalent Safety Evaluation and Rationale for Rules and Requirements Specified in the 2007 and 2021 Editions of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Determination
		Requirements in Part 9 provides the acceptable methods and requirements for overpressure protection for pressure vessels constructed to the requirements of this Division. Acceptable methods include pressure relief devices, open flow paths, and overpressure protection by system design. Part 9 establishes the type, quantity and settings of acceptable pressure relief devices, and relieving capacity requirements including maximum allowed relieving pressures. Unless otherwise specified, the required pressure relief devices shall be constructed, capacity certified, and bear the ASME Certification Mark in accordance with Section XIII. In addition, Part 9 provides requirements for installation of pressure relief devices.	evaluation of overpressure protection rules between the 2007 and 2021 edition of Section VIII, Division 1 of the ASME BPVC was not performed.
8.3	Overpressure Protection by System Design	Paragraph 9.5 – Permitted Pressure Relief Devices and Methods states that protection against overpressure shall be provided by pressure relief devices, open flow paths or system design, or a combination. Paragraph 9.5*(e)* permits protection by system design in accordance with requirements provided in Section XIII, Part 13 as follows. • For vessels with overpressure protection by system design where the pressure is self-limited at or below the vessel MAWP, (see Section XIII, 13.2), there shall be no credible overpressure scenario in which the pressure exceeds the MAWP of the pressurized equipment at the coincident temperature. • For vessels with overpressure protection by system design where the pressure is not self-limited at or below the vessel MAWP (see Section XIII, 13.3), there shall be no credible overpressure scenario in which the pressure exceeds 116% of the MAWP times the ratio of the allowable stress value at the temperature of the overpressure scenario to the allowable stress value at the vessel design temperature. The overpressure limit shall not exceed the vessel test pressure.	Due to restructuring of paragraphs in the 2021 edition and transferring to Section XIII, a comprehensive equivalent safety evaluation of overpressure protection rules between the 2007 and 2021 edition of Section VIII, Division 1 of the ASME BPVC was not performed.

Table 9.4 Evaluation of equivalent safety for rules and requirements revised or added to the 2021 edition of Section I of the ASME BPVC

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section I of the ASME BPVC	Equivalent Safety Evaluation
PG-5 General	PG-5.6 P-No. 15E, Group 1 Materials adds rules for P-No. 15E, Group 1 materials that are heated to temperatures over 1,445°F	This rule adds restrictions to the manufacture or erection of P-No. 15E, Group 1 components to ensure that acceptable

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section I of the ASME BPVC	Equivalent Safety Evaluation
	(785°C) during manufacturing or erection. See Table 9.1 – Base Metal Grouping.	material properties are maintained. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
PG-9 Pipes, Tubes, and Pressure-Containing Parts	PG-9.2 adds Inconel 625 (UNS N06625) under SB-443, SB-444, and SB-446 and UNS N06022 under SB-462, SB-574 and SB-575 for use in steam service to the list of materials specified in the 2007 edition of Section I of the ASME BPVC that are permitted for boiler construction.	This rule permits use of additional materials for boiler construction that are intended for high-temperature service (e.g., superheater). Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
PG-16 General	PG-16.6 was added and states: The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters shall be considered nominal, and allowable tolerances or local variances should be considered acceptable when based on engineering judgment and standard practices as determined by the designer. PG-16.7 was added and states: The dimensional symbols used in the design formulas throughout this Code do not include any allowance for corrosion, erosion, and forming, except where noted. Additional thickness should be provided where these allowances are applicable. See Sect. 5.2 of this report.	This requirement establishes acceptance criteria for unspecified tolerances. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety. This requirement establishes the basis for using dimensional symbols in design formulas for corrosion, erosion, and forming allowances when applicable. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
PG-20 Cold Forming of Carbon, Carbon-Molybdenum, and Creep Strength Enhanced Ferritic Steels	PG-20 was added and states: The cold-formed areas of pressure-retaining components manufactured of carbon steel, carbon-molybdenum steel, and creep strength enhanced ferritic steel alloys shall be heat treated and examined as described below and as listed in Table PG-20, as applicable. Cold forming is defined as any forming method that is performed at a temperature below 1,300°F (705°C) and produces strain in the material. The calculations of strain shall be made in accordance with PG-19.	This rule adds directives for cold forming of carbon, carbon-molybdenum, and creep strength enhanced ferritic steels that involve heat treating and examination. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
PG-38 Compensation for Multiple Openings	PG-38-1 was revised to state: No portion of the cross section shall be considered as applying to more than one opening or be evaluated more than once in a combined area. The available area of the head or shell between openings having an overlap area	This requirement clarifies rules related to multiple openings with overlapping limits of reinforcement. It is now clear how to proportion areas between openings and how to reinforce openings consistent with Section VIII, Division 1. Revision of

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	shall be proportioned between the two openings by the ratio of their diameters.	this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
PG-44 Inspection Openings	PG-44.1 was added and states: All boilers or parts thereof shall be provided with suitable manhole, handhole, or other inspection openings for examination or cleaning, except for special types of boilers where such openings are manifestly not needed or used.	This requirement establishes criteria for manhole, handhole, or other inspection openings for examination or cleaning. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
PG-48 Location of Staybolts	PG-48.1 was added and states: For staybolts adjacent to the riveted edges bounding a stayed surface, the value of p in PG-46 eqs. (1) and (2) may be taken as the distance from the edge of a staybolt hole to a straight-line tangent to the edges of the rivet holes [see Figure A-8, illustrations (g-1) and (g-2)].	This requirement establishes acceptable edge distances for staybolt holes. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
PG-50 Drilled Holes not Penetrating Through a Vessel Wall	PG-50 was added and states: Radially drilled holes for instrumentation probes, which do not penetrate through the thickness of a shell, header, or head, may be considered as having inherent reinforcement, provided the following requirements are met:	This requirement establishes acceptable standards for radially drilled holes for instrumentation probes that do not penetrate through the thickness of a shell, header, or head. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
PG-56 Loading on Structural Attachments	PG-56 was added and states: Loads imposed on steel tube walls by welded or mechanical attachments, which produce bending stresses that are additive to bursting stresses, shall conform to PG-56.1.1 and PG-56.1.2. Alternatively, stresses at structural attachments may be evaluated using one of the three methods specified in PG-56.1. PW-43 in the 2007 edition of Section I was redesignates to PG 56 in the 2019 edition.	This requirement specifies methods for evaluating loads imposed on steel tube walls by welded or mechanical attachments which produce bending stresses that are additive to bursting stresses. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
PG-58 Boiler External Piping (BEP)	PG-58 was revised in its entirety. PG-58.1 General states: The rules of this subparagraph apply to the boiler external piping as defined in the Preamble. All boiler external piping connected to a boiler for any purpose shall be attached to one of the types of joints listed in PG-59.1.1.1, PG-59.1.1.2, and PG-59.1.1.3 and is subject to the requirements of PG-104 for proper Code certification.	This rule clarifies rules for boiler external piping connected. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
PG-60 Design and Application	PG-60.1.2 was redesignated and revised to state: If either the top or bottom valve is more than 7 ft (2 m) above the floor or	This requirement increases or ensures the likelihood of periodic blowing down of gage glasses in a safer manner. Revision of

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Requirements for Miscellaneous Pipe, Valves, and Fittings	platform from which it is operated, the operating mechanism shall indicate by its position whether the valve is open or closed. A means of manually opening and closing the valves from the valve operating floor or platform shall be provided.	this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
PG-69 Certification of Capacity of Pressure Relief Valves	PG-69 was revised to include alternative method for determining the capacity of pressure relief valves. The three alternative methods are prescribed in PG-69.2.4, 69.2.5, and 69.2.6.	This requirement adds rules to calculate pressure relief valve relieving capacities for pressures greater than 3,200 psig. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
PG-73 Minimum Requirements for Pressure Relief Valves	PG-73 was revised to include: PG-73.1 Permissible Pressure Relief Valves PG-73.2 Minimum Requirements PG-73.3 Material Selections PG-73.1 was revised to states: PG-73.1.1 Pressure relief valves shall be either direct spring-loaded safety valves, direct spring-loaded safety relief valves, or pilot-operated pressure relief valves. PG-73.1.2 Power-actuated pressure-relieving valves shall only be used for applications specified in PG-67.4.1. PG-73.1.3 Deadweight or weighted lever safety valves or safety relief valves shall not be used. PG-73.1.4 Unless otherwise defined, the definitions relating to pressure relief devices in ASME PTC 25 shall apply. PG-73.2 adds requirements that state: PG-73.2.1 All pressure relief valves shall be so constructed that the failure of any part cannot obstruct the free and full discharge of steam and water from the valve. Pressure relief valves shall have the seat inclined at any angle between 45 deg and 90 deg, inclusive, to the centerline of the disk. PG-73.2.10 Valve capacity may be restricted by restricting the lift of a valve provided the following requirements are met:	This revision to PG-73.1 adds requirement in for the types of pressure relief valves that are and are not permitted for Section I boilers. This includes incorporation of a Code Case to allow restricted lift pressure relief devices. Pressure relief valves are frequently oversized for required small relief rates. Although oversizing is conservative, it can lead to other difficulties. Therefore, it may be advantageous to limit the capacity to only that required. Physically restricting the lift is an inexpensive and simple option. This revision to PG-73.2 adds minimum requirements in PG-73.2 for pressure relief valves for use on Section I boilers. This addition of PG-73.3 adds requirements for material that are permitted and prohibited for use in pressure relief valve construction. Additions and revisions to these requirements does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.

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	PG-73.2.11 A pressure relief valve over NPS 3 (DN 80), used for pressure greater than 15 psig (100 kPa), shall have a flanged inlet connection or a welded inlet connection. PG-73.2.12 The pilot sensing line of pilot-operated pressure relief valves shall be adequately protected from freezing. PG-73.3 adds requirements for materials that are permitted and prohibited for use in pressure relief valve construction. PG-73.3.1 Cast iron seats and disks are not permitted.	
PG-77 Material Identification	PG-77 Material Identification was retitled and revised to state: The Manufacturer shall describe, in their written Quality Control System, the process for maintaining identification of the pressure part materials as to the type of material.	This revision adds requirements for identification of materials rather than plate material only. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
PW-9 Design of Welded Joints	PW-9 was revised and adds rules for design of specific types of welded joints including: PW-9.3 Transitions at Butt Joints Between Materials of Unequal Thickness PW-9.3.1 Shells, Drums, and Vessels (Including Those Fabricated from Materials Complying with Piping or Tubing Material Specifications). PW-9.3.2 Pipes and Tubes. PW-9.3.3 Heads Attached to Shells.	This revision adds rules for design of specific types of welded joints adopted from Section VIII, Division 1. Addition of these rules does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
PW-16 Minimum Requirements for Attachment Welds	PW-16.7 was added and states: The minimum throat dimensions of fillet welds defined in PW-16.2 shall be maintained around the circumference of the attachment, except as provided below. PW-16.8 was added and states: Partial-penetration-weld-type tube-to-header nozzles and other connections such as shown in Figure PW-16.1, illustrations (y-1) and (z-1), constructed with	This rule recognizes and makes it clear that for radial nozzles, if a constant fillet weld leg size is maintained around the circumference of the nozzle, the throat of the fillet weld is reduced at the circumferential plane of the shell at the shell-to-nozzle joint. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety. This rule adds design criteria for partial-penetration-weld-type tube-to-header nozzles and other connections constructed with ferritic materials and designed for 900°F (480°C) or higher

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	ferritic materials and designed for 900°F (480°C) or higher service, shall be designed to avoid an accumulation of oxide between the nozzle end and the seat.	service. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
PW-17 Forged Flat Heads with Integral Hubbed Flange	PW-17 was added to states: The hub shall be integrally forged with the flat head by direct forging action or machined from a forging. Plate, bar, or rod shall not be used in lieu of a forging.	This rule adds directives for forged flat heads with integral hubbed flange and alternative material forms for use in lieu of forgings. This rule addition does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and is therefore considered equivalent safety.
PW-27 Welding Processes	PW-27 was revised to state: The welding processes that may be used under this Part shall meet all the test requirements of Section IX and are restricted to PW-27.1 through PW 27.4. PW-27.1 states: The following welding processes may be used for any Section I construction: shielded metal arc, submerged arc, gas metal arc, hybrid plasma-gas metal arc, flux cored arc, gas tungsten arc, plasma arc, atomic hydrogen arc, oxyhydrogen, oxyacetylene, laser beam, electron beam, flash, induction, pressure thermit, pressure gas, and inertia and continuous drive friction welding.	This requirement was revised to permits the hybrid plasma-gas metal arc welding process for boiler construction. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
PW-36 Miscellaneous Welding Requirements	PW-36.3 was added and states: When attachment welds are made to the clad portion of pressure parts constructed from P-No. 5B, P-No. 6, or P-No. 15E and other creep-strength-enhanced ferritic steels having weld metal buildup or corrosion-resistant weld metal overlay, the rules of PW-44.2(a) and PW-44.2(b) shall be followed.	This requirement establishes criteria for making attachment welds to clad portion of pressure parts. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
PW-44 Fabrication Rules for Bimetallic Tubes When the Clad Strength is Included	PW-44.1 was added and includes extensive rules and requirements for fabrication rules for bimetallic tubes when the clad strength is included. These rules include a revised equation that uses a concept from Section VIII, Division 1, Part UCL, in which cladding strength is included in the calculated strength of the vessel. Visual and Liquid Penetrant Examination Requirements specified in PW-49 are discussed in Sect. 6.2.1.4 of this report. See Sect. 6.2.1 of this report.	These rules and requirements establish criteria for fabricating bimetallic tubes when the clad strength is included. Addition of these rules and requirements do not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.

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PW-54 Hydrostatic Test	PW-54.1 was revised to state: Welded pressure parts shall be subjected to a hydrostatic test with the completed boiler in accordance with PG-99. The hydrostatic test may be made either in the Manufacturer's shop or in the field. See Sect. 7.1.1.1 of this report.	This requirement clarifies rules for welded pressure parts used for construction of a boiler that are required to be pressure tested with the completed boiler. Addition of this requirement clarification does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Part PR – Requirements for Boilers Fabricated by Riveting PR-1 Scope	PR-1 was revised to state: The rules in this Part are applicable to boilers and component parts thereof that are fabricated by riveting. These rules shall be used in conjunction with the general requirements in the applicable Parts of this Section and Mandatory Appendix V that pertain to the type of boiler under consideration.	This revision adds updated rules for boilers fabricated by riveting. Addition of these revised requirements does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Part PA Alternative Rules for Boiler Construction PA-1 General	Part PA was added and PA-1 General states: Components designed and constructed to the rules of Section VIII, Division 2 may be installed in a Section I boiler, provided all other requirements of Section I are satisfied by a Section I certificate holder and the requirements of Part PA are met.	This requirement establishes criteria for design and construction of components for Section I boilers that comply with the rules of Section VIII, Division 2. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Part PWT – Requirements for Watertube Boilers PWT-12 Staybolting Box-Type Headers and Waterlegs	PWT-12 was revised to state: The front and back sheets of staybolted box-type headers and waterlegs may be joined together by welding by any of the methods described in PFT-21 for fireboxes and waterlegs, provided the thickness and header width requirements of PFT-21 and Figure PFT-21 are met.	This requirement adds rules for staybolting box-type headers and waterlegs for watertube boilers. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Part PFT – Requirements for Firetube Boilers PFT-20 Attachment of Furnaces	PFT-20.3 was revised to state: A furnace may be attached by a full penetration weld with the furnace extending at least through the full thickness of the tubesheet or head but not beyond the toe of the weld, and the toe shall not project beyond the face of the tubesheet or head by more than 3/8 in. (10 mm) unless protected from overheating by refractory material or other means. Alternatively, the furnace may abut the tubesheet or head with a full-penetration weld made through the furnace. The weld may be applied from either or both sides and shall have an external fillet weld with a minimum throat of ¼ in. (6 mm). No weld preparation machining shall be performed on the flat tubesheet or head. The edge of the tubesheet or head shall be examined	This revision adds alternative rules for full penetration weld construction for furnace attachments. Addition of these revised requirements does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.

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	when required by PG-93 and shall not extend beyond the edge of the furnace by more than 3/8 in. (10 mm) unless protected from overheating by refractory material or other means.	
Part PFT – Requirements for Firetube Boilers PFT-40 Welded Door Openings	PFT-40 was revised to state: Welding may be used in the fabrication of door holes provided the sheets are stayed around the opening in accordance with the requirements of PFT-27.6 and PFT-27.7. No calculations need be made to determine the availability of compensation for door openings spanning between the plates of waterlegs. The required thickness of circular access openings shall be determined in accordance with PG-28.3. The required thickness of door openings of other than circular shape shall be calculated using eq. PG-46.1*(1)*, using 2.1 or 2.2 for the value of C, depending on the plate thickness, and a value of p equal to the waterleg inside width. Volumetric examination of the joining welds is not required.	This requirement adds rules for welding processes permitted for welded door openings. Addition of these revised requirements does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Part PFT – Requirements for Firetube Boilers PFT-50 Thickness of Furnaces and Tubes Under External Pressure (PFT-50 in the 2007 edition was redesignates to PG 28.1 in the 2021 edition.)	PFT-50.1 states: The design temperature shall be not less than the maximum expected mean wall temperature established by calculation or measurement. As an alternative to calculating or measuring the maximum expected mean metal temperature, 700°F (370°C) may be used as the design temperature. See Sect. 4.1.1.1 of this report.	This revision redesignates requirements for thickness of furnaces and tubes under external pressure from PFT-50 in the 2007 edition to PG 28.1 in the 2019 edition. See Sect. 4.1.1.1 of this report. Addition of this redesignation does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Part PFT – Requirements for Firetube Boilers PFT-51 Maximum Allowable Working Pressure (PFT-51 in the 2007 edition was redesignates to PG 28.1 in the 2021 edition.)	PFT-51.1 states: The maximum allowable working pressure of tubes, flues, plain circular, and ring reinforced furnaces of firetube boilers shall be as determined by the following rules. External pressure charts for use in determination of minimum requirements are given in Section II, Part D, Subpart 3. See Sect. 4.1.1.1 of this report.	This revision redesignates maximum allowable working pressure requirements of tubes, flues, plain circular, and ring reinforced furnaces of firetube boilers from PFT-51 in the 2007 edition to PG 28.3 in the 2021 edition. See Sect. 4.1.1.1 of this report. Addition of this redesignation does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.

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Part PFH – Optional Requirements for Feedwater Heater PTFH Requirements for Liquid Phase Thermal Fluid Heaters	Part PTFH was added and PTFH-1 General states: The rules in Part PTFH are applicable to liquid phase thermal fluid heaters and parts thereof and shall be used in conjunction with the general requirements in Part PG as well as with the special requirements of this Part that apply to the method of fabrication used. The rules in this Part do not apply to solar boiler molten salt receivers.	These requirements establish criteria for liquid phase thermal fluid heaters and parts thereof, but they do not apply to solar boiler molten salt receivers. Addition of these requirements do not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Part PMB – Requirements for Miniature Boilers PMB 13 Water Level Indicators	PMB-13.1 was revised to state: Each miniature boiler for operation with a definite water level shall be equipped with a gage glass for determining the water level. The lowest permissible water level of vertical boilers shall be at a point one-third of the height of the shell above the bottom head or tubesheet. Where the boiler is equipped with an internal furnace, the lowest permissible water level shall be not less than one-third of the length of the tubes above the top of the furnace tubesheet. In the case of small boilers operated in a closed system where there is insufficient space for the usual gage glass, water level indicators of the glass bull's-eye type may be used.	This revision clarifies requirements for gage glasses for miniature boilers. Addition of this revision do not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Part PEB – Requirements for Electric Boilers PEB-2 Scope	PEB-2.5 was added and states: Electric boilers may be field assembled provided the boiler is manufactured and assembled in compliance with the provisions and requirements of Part PEB and other applicable Parts of this Section.	This requirement increases the scope of Part PEB Requirements for Electric Boilers to permit field assembly of electric boilers. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Part PEB – Requirements for Electric Boilers PEB-3 Optional Requirements for the Boiler Pressure Vessel	PEB-3.1.1 was added to PEB 3.1 to state: Welds shall be postweld heat treated to the minimum holding time and temperature requirements of Section VIII, Division 1 unless the welds satisfy the exemptions for postweld heat treatment in both Section I and Section VIII, Division 1.	This requirement adds construction options for boiler pressure vessels. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Part PVG – Requirements for Organic Fluid Vaporizers	PVG-12.2 was revised to state: Pressure relief valves should be disconnected from the vaporizer at least once yearly (or as recommended by the vaporizer Manufacturer or valve manufacturer). If disconnected, the pressure relief valve should	This requirement revises pressure relief valves requirements for organic fluid vaporizers. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.

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PVG-12 Pressure Relief Valves	be inspected, repaired if necessary, tested, and then replaced on the vaporizer.	
Part PFE – Requirements for Feedwater Economizers Part PFE – Requirements for Feedwater Economizers	Part PFE was added and PFE-1 General states: A feedwater economizer is a heat exchanger in which feedwater to be supplied to a boiler is heated by flue gases exiting the boilers. When an economizer is provided with a Section I boiler and resides within the limits of boiler external piping, it shall be constructed in accordance with Section I rules. When the economizer is located outside the limits of boiler external piping, the economizer shall be constructed in accordance with the rules of either Section I or Section VIII, Division 1.	This requirement establishes criteria for construction of feedwater economizers that are provided with a Section I boiler. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Part PHRSG – Requirements for Heat Recovery Steam Generators PHRSG-3 Requirements for Superheater and Reheater Condensate Removal Connections	PHRSG-3.4 was revised to state: All condensate removal piping systems shall be made up of drain piping and two drain valves in series and be routed to a blowdown tank, flash tank, manifold, or other collection device. The piping and valves shall provide draining capacity such that condensate pooling in superheaters and reheaters is prevented. The collection device shall not be operated at a higher pressure than the space being drained.	This requirement revises rules for superheater and reheater condensate removal connections for heat recovery steam generators (HRSG). Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Part PHRSG – Requirements for Heat Recovery Steam Generators PHRSG-3 Requirements for Superheater and Reheater Condensate Removal Connections	PHRSG-3.5 was added to state: When the HRSG is a multiple pressure steam generator (See PG 106.12), the requirements of PHRSG-3.1 through PHRSG-3.4 apply only to the superheater sections of the high-pressure section and to each reheater. Drain requirements of PG-59.4 are applicable for superheater sections not covered by PHRSG-3.	This requirement adds rules for superheater drains. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix I Submittal of Technical Inquiries to the Boiler and Pressure Vessel Committee	Mandatory Appendix I was included in the 2007 edition but deleted from the 2021 edition. The 2021 edition includes Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees as part of the front matter in Section I.	This requirement for Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees in the 2007 edition is included as part of the front matter in Section I of the 2021 edition of the ASME BPVC. Relocating this requirement to the front matter in Section I of the 2021 edition of the ASME BPVC does not violate the fundamental safety assumptions

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		stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix II Standard Units for Use in Equations	Mandatory Appendix II Standard Units for Use in Equations was included in the 2007 edition but was redesignated as Paragraph PG 4 in Section I of the 2021 edition of the ASME BPVC.	This requirement for Standard Units for Use in Equations in the 2007 edition was redesignated as Paragraph PG 4 in Section I of the 2021 edition of the ASME BPVC. Relocating this requirement to Paragraph PG 4 in Section I of the 2021 edition of the ASME BPVC does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix III Criteria for Reapplication of a Certification Mark	Mandatory Appendix III was added and state: After an item has been certified under ASME Section I, if the stamping of the Certification Mark with appropriate Designator becomes indistinct or the nameplate is illegible or lost, but traceability to the original certification can be established, the Certification Mark may be reapplied to the item. For the purpose of this Mandatory Appendix, application of the Certification Mark with the appropriate Designator shall be equivalent to the Code Symbol stamping required by earlier Code editions and addenda. Reapplication of the Certification Mark shall only be permitted under the five conditions defined in III-2 as discussed in Sect. 2.1 of this report.	This requirement establishes criteria for reapplication of a Certification Mark under five specified conditions. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix IV Local Thin Areas in Cylindrical Shells and in Spherical Segments of Heads	Mandatory Appendix IV was added and states: The rules of this Mandatory Appendix permit the thickness of local thin areas (LTAs) to be less than the required thickness under the three conditions specified in IV-1 – Scope.	This requirement establishes criteria for use of local thin areas under the three conditions specified in IV-1 Scope and incorporates Code Cases 2330-1 – Local Thin Areas in Spherical Segments of Heads and Code Case 2331-1 – Local Thin Areas in Spherical Segments of Heads. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix V Additional Rules for Boilers Fabricated by Riveting	Mandatory Appendix V was added and states: The rules of this Mandatory Appendix are for boilers or component parts thereof that are fabricated by riveting.	These rules and requirements establish criteria for fabricating boilers or component by riveting. Addition of these rules and requirements do not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix VI	Mandatory Appendix VI was added and states: After Code revisions are approved by ASME, they may be used beginning	This requirement defines criteria for establishing governing Code editions, addenda, and cases for boilers and replacement

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Establishing Governing Code Editions, Addenda, and Cases for Boilers and Replacement Parts	with the date of issuance shown on the Code. Except as noted below, revisions become mandatory 6 months after the date of issuance. Code Cases are permissible and may be used beginning with the date of approval by ASME as discussed in Sect. 2.1 of this report.	parts. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix VII Alternate Methods for Applying the ASME Certification Mark	Mandatory Appendix VII was added and VII-1 – Requirements for Alternate Methods states: Acceptable alternate methods include etching (laser, plasma, or chemical), peening, and engraving, and the external surface condition where the marking is to be applied shall be clean, uncoated, and unpainted.	This requirement defines acceptable alternate methods for applying the ASME Certification Mark. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Nonmandatory Appendix B Positive Material Identification Practice	Nonmandatory Appendix B was added and Paragraph B-1 – Introduction states: As part of his material control system, a Manufacturer may determine that a situation warrants positive material identification for a specific material or item. This Nonmandatory Appendix is provided as a guide for use by the Manufacturer in developing a Positive Material Identification Practice (PMIP) that may be applied to address the material or item of concern.	This requirement adds guidelines for positive material identification practices. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Nonmandatory Appendix C Local Heating of Welds in Cylindrical Components of P-No. 15E Materials When Using Electric Resistance Heating	Nonmandatory Appendix C was added and Paragraph C-1 – Scope states: The rules of this Appendix describe the minimum requirements that are to be followed during the setup and application of local controlled heat to weld joints, as opposed to heating the complete weldment in a furnace or oven. This Appendix applies specifically to the heating of P-No. 15E materials when using electric resistance heating pads.	This requirement establishes criteria for local heating of welds in cylindrical components of P-No. 15E materials when using electric resistance heating. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety. The 2019 edition adds rules that describe the minimum requirements that are to be followed during the setup and application of local controlled heat to weld joints.
Nonmandatory Appendix D Design Guidelines for Corrosion, Erosion, and Steam Oxidation of Boiler Tubes	Nonmandatory Appendix D was added and Paragraph D-1 – Introduction states: This Appendix provides an overview of guidelines for boiler design engineers and others aimed at minimization of the effects of fireside corrosion, particle impact erosion, and steam-side oxidation on boiler tubing and other components of coal-fired boilers. Gas- and oil-fired boiler wastage are excluded.	This requirement adds design guidelines for minimizing the effects of fireside corrosion, particle impact erosion, and steam-side oxidation on boiler tubing and other components of coal-fired boilers. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section I of the ASME BPVC	Equivalent Safety Evaluation
Nonmandatory Appendix E Alternative Method for Ultrasonic Examination	Nonmandatory Appendix E was added and Paragraph E-1 – Introduction states: In lieu of the ultrasonic examination requirements of PW 52, automated or semi-automated ultrasonic examination may be performed in accordance with a written procedure conforming to the requirements of Section V, Article 4, Mandatory Appendix VIII, a qualification standard prepared in accordance with Section V, Article 4, Mandatory Appendix IX, and the following additional requirements.	This requirement defines alternative method for ultrasonic examination in lieu of the ultrasonic examination requirements of PW 52. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.
Nonmandatory Appendix F Design Guidelines for Dissimilar Metal Welds Between CSEF and Austenitic Stainless Steels	Nonmandatory Appendix F was added and Paragraph F-1 – Introduction states: This Appendix provides important guidelines regarding the design, fabrication, and construction of dissimilar metal welds (DMWs) between creep strength enhanced ferritic (CSEF) steel and austenitic stainless-steel components designed to transport or collect steam.	This requirement adds design, fabrication, and construction guidelines for dissimilar metal welds between creep strength enhanced ferritic (CSEF) and austenitic stainless-steel components designed to transport or collect steam. Addition of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety.

Table 9.5 Evaluation of equivalent safety for rules and requirements revised or added to the 2021 edition of Section II of the ASME BPVC

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section II of the ASME BPVC	Equivalent Safety Evaluation
Part A Ferrous Material Specifications		
Corrosion-Resisting and Heat-Resisting Steels	The 2021 edition of Section II, Part A adds SA/EN 10088-2 Specification for Stainless Steels Part 2: Technical Delivery Conditions for Sheet/Plate and Strip of Corrosion Resisting Steels for General Purposes.	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Corrosion-Resisting and Heat-Resisting Steels	The 2021 edition of Section II, Part A adds SA/EN 10088-3 Specification for Stainless Steel Part 3: Technical Delivery Conditions for Semi-Finished Products, Bars, Rods, Wire, Sections, and Bright Products of Corrosion Resisting Steels for General Purposes.	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Methods	SA-275/SA-275M is not included in the 2021 edition of Section II, Part A.	An equivalent safety evaluation is not possible.
Steel Bars	The 2021 edition of Section II, Part A adds SA/JIS G4303 Specification for Stainless Steel Bars.	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Steel Billets and Forgings	The 2021 edition of Section II, Part A adds SA/EN 10222-2 Specification for Steel Forgings for Pressure Purposes Part 2: Ferritic and Martensitic Steels with Specified Elevated Temperature Properties.	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Steel Castings	SA-494/SA-202M is not included in the 2021 edition of Section II, Part A.	An equivalent safety evaluation is not possible.
Steel Plate, Sheet, and Strip	The 2021 edition of Section II, Part A adds SA/NF A 36-215 Specification for Weldable Fine Grain Steels for Transportation of Dangerous Substances.	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Steel Plates, Sheets, and Strip for Pressure Vessels	SA-202/SA-202M is not included in the 2021 edition of Section II, Part A.	An equivalent safety evaluation is not possible.
Steel Plates, Sheets, and Strip for Pressure Vessels	The 2021 edition of Section II, Part A adds SA/EN 10028-4 Specification for Flat Products Made of Steels For Pressure Purposes Part 4: Nickel Alloy Steels With Specified Low Temperature Properties.	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section II of the ASME BPVC	Equivalent Safety Evaluation
Steel Plates, Sheets, and Strip for Pressure Vessels	The 2021 edition of Section II, Part A adds SA/EN 10028-7 Specification for Flat Products Made of Steels for Pressure Purposes Part 7: Stainless Steels.	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Steel Plates, Sheets, and Strip for Pressure Vessels	The 2021 edition of Section II, Part A adds SA/GB 713 Specification for Steel Plates for Boilers and Pressure Vessels.	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Steel Plates, Sheets, and Strip for Pressure Vessels	The 2021 edition of Section II, Part A adds SA/JIS G3118 Specification for Carbon Steel Plates for Pressure Vessels for Intermediate and Moderate Temperature Service.	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Steel Tubes	The 2021 edition of Section II, Part A adds SA/EN 10216-2 Specification for Seamless Steel Tubes for Pressure Purposes Part 2: Technical Delivery Conditions for Non-Alloy and Alloy Steel Tubes with Specified Elevated Temperature Properties.	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Steel Tubes	The 2021 edition of Section II, Part A adds SA/EN 10217-1 Specification for Welded Steel Tubes for Pressure Purposes Part 1: Technical Delivery Conditions for Non-Alloy Steel Tubes with Specified Room Temperature Properties.	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Structural Steel	The 2021 edition of Section II, Part A adds SA/EN 10025-2 Specification for Hot Rolled Products of Structural Steels Part 2: Technical Delivery Conditions for Non-Alloy Structural Steels.	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Structural Steel	The 2021 edition of Section II, Part A adds SA/IS 2062 Specification for Steel for General Structural Purposes.	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Wrought Iron, Cast Iron, and Malleable Iron	The 2021 edition of Section II, Part A adds SA/JIS G5504 Specification for Heavy-Walled Ferritic Spheroidal Graphite Iron Castings for Low Temperature Service.	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Part A Mandatory Appendices		
Mandatory Appendix II Basis for Use of Acceptable ASME, ASTM, and Non-ASTM Editions	The 2021 edition of Section II, Part A adds Mandatory Appendix II. Paragraph II-100 – Materials Adopted for Use in Construction Codes states: The specifications for the materials given in Section II, Parts A and B are identical with or similar to those specifications published by ASTM and other recognized national or international organizations. Not all grades, classes,	Addition of this mandatory appendix does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section II of the ASME BPVC	Equivalent Safety Evaluation
	and types of materials included in the material specifications have been adopted for Code use.	
Mandatory Appendix III Guidelines on Multiple Marking of Materials	The 2021 edition of Section II, Part A adds Mandatory Appendix III. III-100 – Background states: A common inquiry topic is the permissibility of using material that is identified with two or more specifications (or grades, classes, or types), even if they have different strengths, or even if one of them is not permitted for use in the construction code of application. The Committee has addressed variants of these questions in several interpretations: I-8911, IIA-92-08, VIII-1-89-269, and VIII-1-89-197.	Addition of this mandatory appendix does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix IV Guidelines on the Approval of New Materials Under the ASME Boiler and Pressure Vessel Code	The 2021 edition of Section II, Part A adds Mandatory Appendix IV. Paragraph IV-100 – Code Policy states: It is expected that requests for Code approval will normally be for materials for which there is a recognized national or international specification. It is the policy of the ASME Boiler and Pressure Vessel (BPV) Committee on Materials to approve, for inclusion in the Code Sections, only materials covered by specifications that have been issued by standards-developing organizations such as, but not limited to, American Petroleum Institute (API), American Society for Testing and Materials (ASTM), American Welding Society (AWS), Canadian Standards Association (CSA), European Committee for Standardization (CEN), Japan Industrial Standards (JIS), Standards Association of Australia (SAA), and China Standardization Committee (CSC).	Addition of this mandatory appendix does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Part B Nonferrous Material Specifications		
Aluminum and Aluminum Alloys	The 2021 edition of Section II, Part B adds SB-666/SB-666M Practice for Identification Marking of Aluminum and Magnesium Products.	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Copper and Copper Alloy Pipe and Tubes	SB-706 Specification for Seamless Copper Alloy (UNS No. C69100) Pipe and Tube is not included in the 2021 edition of Section II, Part B.	An equivalent safety evaluation is not possible.
Copper and Copper Alloy Pipe and Tubes	SB-956/SB-956M Specification for Welded Copper and Copper-Alloy Condenser and Heat Exchanger Tubes with	An equivalent safety evaluation is not possible.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section II of the ASME BPVC	Equivalent Safety Evaluation
	Integral Fins is not included in the 2021 edition of Section II, Part B.	
Nickel and Nickel Alloy Rod, Bar, and Wire	SF-467 Specification for Nonferrous Nuts for General Use is not included in the 2021 edition of Section II, Part B.	An equivalent safety evaluation is not possible.
Nickel and Nickel Alloy Rod, Bar, and Wire	SF-467M Specification for Nonferrous Nuts for General Use [Metric] is not included in the 2021 edition of Section II, Part B.	An equivalent safety evaluation is not possible.
Nickel and Nickel Alloy Rod, Bar, and Wire	SF-468 Specification for Nonferrous Bolts, Hex Cap Screws, and Studs for General Use is not included in the 2021 edition of Section II, Part B.	An equivalent safety evaluation is not possible.
Nickel and Nickel Alloy Rod, Bar, and Wire	SF-468M Specification for Nonferrous Bolts, Hex Cap Screws, and Studs for General Use [Metric] is not included in the 2021 edition of Section II, Part B.	An equivalent safety evaluation is not possible.
Zirconium and Zirconium Alloys	SB-653/SB-653M Specification for Seamless and Welded Zirconium and Zirconium Alloy Welding Fittings is not included in the 2021 edition of Section II, Part B.	An equivalent safety evaluation is not possible.
Part B Mandatory Appendices		
Mandatory Appendix II Basis for Use of Acceptable ASME, ASTM, and Non-ASTM Editions	The 2021 edition of Section II, Part B adds Mandatory Appendix II. Paragraph II-100 Materials Adopted for Use in Construction Codes states: The specifications for the materials given in Section II, Parts A and B are identical with or similar to those specifications published by ASTM and other recognized national or international organizations. Not all grades, classes, and types of materials included in the material specifications have been adopted for Code use.	Addition of this mandatory appendix does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix III Guidelines on Multiple Marking of Materials	The 2021 edition of Section II, Part B adds Mandatory Appendix III. Paragraph III-100 Background states: A common inquiry topic is the permissibility of using material that is identified with two or more specifications (or grades, classes, or types), even if they have different strengths, or even if one of them is not permitted for use in the construction code of application. The Committee has addressed variants of these	Addition of this mandatory appendix does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section II of the ASME BPVC	Equivalent Safety Evaluation
	questions in several interpretations: I-8911, IIA-92-08, VIII-1-89-269, and VIII-1-89-197.	
Mandatory Appendix IV Guidelines on the Approval of New Materials Under the ASME Boiler and Pressure Vessel Code	The 2021 edition of Section II, Part B adds Mandatory Appendix IV. Paragraph IV-100 Code Policy states: It is expected that requests for Code approval will normally be for materials for which there is a recognized national or international specification. It is the policy of the ASME Boiler and Pressure Vessel (BPV) Committee on Materials to approve, for inclusion in the Code Sections, only materials covered by specifications that have been issued by standards-developing organizations such as, but not limited to, American Petroleum Institute (API), American Society for Testing and Materials (ASTM), American Welding Society (AWS), Canadian Standards Association (CSA), European Committee for Standardization (CEN), Japan Industrial Standards (JIS), Standards Association of Australia (SAA), and China Standardization Committee (CSC).	Addition of this mandatory appendix does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Part C Specifications for Welding Rods, Electrodes, and Filler Metals		
Welding Rods, Electrodes, and Filler Metals	The 2021 edition of Section II, Part C adds SFA-5.02/SFA-5.02M Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Welding Rods, Electrodes, and Filler Metals	The 2021 edition of Section II, Part C adds SFA-5.34/SFA-5.34M Specification for Nickel-Alloy Electrodes for Flux Cored Arc Welding	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Welding Rods, Electrodes, and Filler Metals	The 2021 edition of Section II, Part C adds SFA-5.35/SFA-5.35M Specification for Covered Electrodes for Underwater Wet Shielded Metal Arc Welding	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Welding Rods, Electrodes, and Filler Metals	The 2021 edition of Section II, Part C adds SFA-5.36/SFA-5.36M Specification for Carbon and Low-Alloy Steel Flux Cored Electrodes for Flux Cored Arc Welding and Metal Cored Electrodes for Gas Metal Arc Welding	Addition of this material does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section II of the ASME BPVC	Equivalent Safety Evaluation
	Part D Properties Subpart 1 Stress Tables	
Guideline on Locating Materials in Stress Tables, and in Tables of Mechanical and Physical Properties	Paragraph 2 – Stress Tables was revised to state: Stress tables are all found within Subpart 1 of Section II, Part D. Tables 1A, 1B, 3, 5A, and 5B cover allowable stresses, while Tables 2A, 2B, and 4 cover design stress intensities. For this edition, Tables 6A, 6B, 6C, and 6D are provided for information only. The governing allowable stresses for those materials are provided in ASME BPVC, Section IV. Although Subpart 1 also covers ultimate tensile strength and yield strength, the organization of those mechanical property tables will be discussed separately in para. 3. A table-by-table listing of the materials organization logic used to place materials within the designated tables follows.	This revision expands the scope of guideline on locating materials in stress tables, and in tables of mechanical and physical properties. Revision of this guideline does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Guideline on Locating Materials in Stress Tables, and in Tables of Mechanical and Physical Properties	Paragraph 2 – Stress Tables, 2.9 Table 6A states: Table 6A provides allowable stresses for ferrous materials for Section IV construction. This Table is organized in the same manner as Table 1A. Refer back to para. 2.1 for that description.	This revision adds a stress table that includes allowable stresses for ferrous materials for Section IV construction. Revision of this guideline does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Guideline on Locating Materials in Stress Tables, and in Tables of Mechanical and Physical Properties	Paragraph 2 – Stress Tables, 2.10 Table 6B states: Table 6B provides allowable stresses for nonferrous materials for Section IV construction. This Table is organized in the same manner as Table 1B. Refer back to para. 2.2 for that description.	This revision adds a stress table that includes allowable stresses for nonferrous materials for Section IV construction. Revision of this guideline does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Guideline on Locating Materials in Stress Tables, and in Tables of Mechanical and Physical Properties	2.11 Table 6 states: Table 6C provides allowable stresses for Section IV construction of lined water heaters. This Table is organized in the same manner as Table 1A. Refer back to para. 2.1 for that description.	This revision adds a stress table that provides allowable stresses for Section IV construction of lined water heaters. Revision of this guideline does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Guideline on Locating Materials in Stress Tables, and in Tables of Mechanical and Physical Properties	Paragraph 2 – Stress Tables, 2.12 Table 6D states: Table 6D provides allowable stresses for Section IV construction of unlined water heaters. This Table is organized in the same manner as Table 1A. Refer back to para. 2.1 for that description.	This revision adds a stress table that provides allowable stresses for Section IV construction of unlined water heaters. Revision of this guideline does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section II of the ASME BPVC	Equivalent Safety Evaluation
	Part D Mandatory Appendices	
Mandatory Appendix 4 Submittal of Technical Inquiries to the Boiler and Pressure Vessel Committee	The 2021 edition does not include Mandatory Appendix 4.	This addition provides guidance for submittal of technical inquiries to the boiler and pressure vessel standards committees to the front matter of Section II, Part D. Revision of this guidance does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 5 Guidelines on the Approval of New Materials Under the ASME Boiler and Pressure Vessel Code	Paragraph 5-100 – Code Policy was revised in its entirety to state: It is expected that requests for Code approval will normally be for materials for which there is a recognized national or international specification. It is the policy of the ASME Boiler and Pressure Vessel (BPV) Committee on Materials to approve, for inclusion in the Code Sections, only materials covered by specifications that have been issued by standards-developing organizations such as, but not limited to, American Petroleum Institute (API), American Society for Testing and Materials (ASTM), American Welding Society (AWS), Canadian Standards Association (CSA), European Committee for Standardization (CEN), Japan Industrial Standards (JIS), Standards Association of Australia (SAA), and China Standardization Committee (CSC). Material specifications of other than national or international organizations, such as those of material producers/suppliers or equipment manufacturers, will not be considered for approval. The Committee will consider only official requests for specifications authorized by the originating standardization body and available in the English language and in U.S. Customary and/or SI/Metric units.	This revision provides guidelines on the approval of new materials under the ASME boiler and pressure vessel code issued by standards-developing organizations. Revision of this guidelines does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 6 Basis for Establishing Stress Values in Tables 6A, 6B, 6C, and 6D	Paragraph 6-100 – Derivation of Allowable Stress Values states: The values in Tables 6A, 6B, 6C, and 6D are established by the Committee only. In the determination of allowable stress values for materials, the Committee is guided by successful experience in service, insofar as evidence of satisfactory performance is available.	This revision adds an explanation of the basis for establishing stress values in Tables 6A, 6B, 6C, and 6D. Revision of this guidelines does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section II of the ASME BPVC	Equivalent Safety Evaluation
	Part D Nonmandatory Appendices	
Nonmandatory Appendix B Developing Nominal Composition Designations for ASME Code Materials	Paragraph B-100 – Background states: Nominal composition designations play an essential role in the ordering of materials in stress tables for ferrous materials in Section II, Part D of the ASME Boiler and Pressure Vessel Code and in other Sections of the Code containing such tables. In Code stress tables for nonferrous materials, alloys are ordered by increasing Unified Numbering System (UNS) numbers, except that nonferrous alloys without UNS numbers (alloys not listed in an ASTM specification) are listed following similar nonferrous alloys that do have UNS numbers.	This addition provides guidance for developing nominal composition designations for ASME Code materials. Revision of this guidance does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Nonmandatory Appendix D Guidelines for Rounding Minimum Specified Tensile and Yield Strength Values and for Establishing Anchor Points for Tensile and Yield Strength Trend Curves in Tables 1A, 1B, 2A, 2B, 3, 4, 5A, 5B, U, U-2, and Y-1	Nonmandatory Appendix D includes: Paragraph D-100 – Minimum Tensile Strength and Minimum Yield Strength Columns Paragraph D-200 – Selecting Anchor Point for Tensile and Yield Strength Trend Curves for All Situations in which the Minimum RT Specified Values in One Unit System Are Not Precise Conversions of the Units in the Other System Paragraph D-300 – Significant Figures in the Allowable Stress, Tensile Strength, and Yield Strength Tables in Section II Part D and in Code Cases	This addition provides guidelines for rounding minimum specified tensile and yield strength values and for establishing anchor points for tensile and yield strength trend curves. Revision of this guidelines does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.
Nonmandatory Appendix E Material Data for Stress Analysis in the Time-Dependent Regime	Paragraph E-100 – Introduction states: Tables E 100.1-1 through E 100.23-1 and Figures E-100.2-1 through E-100.22--1 were drawn from the 2015 Edition of Section III, Subsection NH. They are intended to be used in the time-dependent stress analysis for nonnuclear applications using the strain method.	This nonmandatory appendix adds material data that are intended to be used in the time-dependent stress analysis for nonnuclear applications using the strain method. Addition of this nonmandatory appendix does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.

Table 9.6 Evaluation of equivalent safety for rules and requirements revised or added to the 2021 edition of Section V of the ASME BPVC

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section V of the ASME BPVC	Equivalent Safety Evaluation
Subsection A – Nondestructive Methods of Examination Article 1 – General Requirements		
T-120 General (See Sect. 6.3.1 of this report.)	T-120 was revised to state: *(e)* For those documents that directly reference this Article for the qualification of NDE personnel, the qualification shall be in accordance with their employer's written practice which shall be in accordance with one of the following documents: *(1)* SNT-TC-1A (2016 Edition), Personnel Qualification and Certification in Nondestructive Testing, as amended by Mandatory Appendix III; or *(2)* ANSI/ASNT CP-189 (2016 Edition), ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel, as amended by Mandatory Appendix IV.	This rule revises the 2001 editions of SNT-TC-1A and ANSI/ASNT CP-189 to the 2016 editions. Rule changes from the 2001 to the 2016 edition affect nondestructive methods of examination because the 2016 editions incorporate additional sections and text revisions. In addition, SNT-TC-1A (2016 Edition) and ANSI/ASNT CP-189 (2016 Edition) increase the recommended certification period for Level I and Level II examiners from 3 years to 5 years. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
T-120 General (See Sect. 6.3.1 of this report.)	T-120 was revised to state: *(f)* National or international central certification programs, such as the ASNT Central Certification Program (ACCP) or ISO 9712:2012-based programs, may be alternatively used to fulfill the training, experience, and examination requirements of the documents listed in *(e)* as specified in the employer's written practice.	This rule revision permit ISO 9712:2012-based programs to be alternatively used to fulfill the training, experience, and examination requirements. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
T-120 General (See Sect. 6.3.1 of this report.)	T-120 was revised to state: *(g)* In addition to the requirements described in *(e)* or *(f)* above, if the techniques of computed radiography (CR), digital radiography (DR), phased-array ultrasonic (PAUT), ultrasonic time-of-flight diffraction (TOFD), or ultrasonic full matrix capture (FMC) are to be used, the training, experience, and examination requirements found in Article 1, Mandatory Appendix II shall also be included in the employer's written practice for each technique as applicable.	This rule revision allows the employer's written practice as applicable for the techniques of computed radiography (CR), digital radiography (DR), phased-array ultrasonic (PAUT), ultrasonic time-of-flight diffraction (TOFD), or ultrasonic full matrix capture (FMC). Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
T-120 General (See Sect. 6.3.1 of this report.)	T-120 was revised to state: *(h)* Alternatively, performance-based qualification programs, in accordance with ASME ANDE-1-2015, ASME Nondestructive Examination and Quality Control Central Qualification and Certification Program, may be	This rule revision permits alternative performance-based qualification programs in accordance with ASME ANDE-1-2015, ASME Nondestructive Examination and Quality Control Central Qualification and Certification Program.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section V of the ASME BPVC	Equivalent Safety Evaluation
	used for training, experience, examination, and certification activities as specified in the written practice.	Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
T-150 Procedure (See Sect. 6.3.1 of this report.)	T-150 was revised to state: *(a)* When required by the referencing Code Section, all nondestructive examinations performed under this Code Section shall be performed following a written procedure. A procedure demonstration shall be performed to the satisfaction of the Inspector. When required by the referencing Code Section, a personnel demonstration may be used to verify the ability of the examiner to apply the examination procedure.	This rule clarifies the differences between procedure and personnel demonstrations, and when each is to be applied. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix I Glossary of Terms for Nondestructive Examination	I-110 – Scope was revised to state: This Mandatory Appendix is used for the purpose of establishing standard terms and the definitions of those terms for Section V.	This rule expands the glossary of terms for nondestructive examination to include standard terms and the definitions of those terms for Section V. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix II Supplemental Personnel Qualification Requirements for NDE Certification	II-110 – Scope states: This Appendix provides the additional personnel qualification requirements that are mandated by Article 1, T-120*(g)*, and which are to be included in the employer's written practice for NDE personnel certification, when any of the following techniques are used by the employer: computed radiography (CR), digital radiography (DR), phased array ultrasonic (PAUT), ultrasonic time of flight diffraction (TOFD), and ultrasonic full matrix capture (FMC).	This revision adds rules for additional personnel qualification requirements for NDE certification. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix II Supplement A	II-A-110 – Training Outline for Level II Personnel defines topical training outlines appropriate for the training of Level II personnel.	This revision adds rules for defining topical training outlines appropriate for the training of Level II personnel. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix III	Mandatory Appendix III states: Where ASNT SNT-TC-1A 2016 Edition has used the verb "should" throughout the document to	This revision adds rules for exceptions and additional requirements for use of ASNT SNT-TC-1A 2016 edition.

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Exceptions and Additional Requirements for Use of ASNT SNT-TC-1A 2016 Edition	emphasize the recommendation presented, Section V has modified many of the "should" statements to designate minimum requirements when SNT-TC-1A is utilized as the basis for the required Written Practice for Section V compliance. Replacing Section V "shall" statements with "should" statements is not allowed.	Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix IV Exceptions to ASNT/ANSI CP-189 2016 Edition	Mandatory Appendix IV states: This Mandatory Appendix is used for the purpose of identifying exceptions to 2016 Edition of ASNT/ANSI CP-189 requirements for "Qualification and Certification of Nondestructive Testing Personnel." The requirements identified in this Mandatory Appendix take exception to those specific requirements as identified in the 2016 Edition of ASNT/ANSI CP-189 document.	This revision adds rules for exceptions to ASNT/ANSI CP-189 2016 edition. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Subsection A – Nondestructive Methods of Examination **Article 2 – Radiographic Examination**		
T-282 Radiographic Density	T-282.1 – Density Limitations was revised to state: The transmitted film density through the radiographic image of the body of the designated hole-type IQI adjacent to the essential hole or adjacent to the essential wire of a wire-type IQI and the area of interest shall be 1.8 minimum for single film viewing for radiographs made with an X-ray source and 2.0 minimum for radiographs made with a gamma ray source.	This revision adds rules to clarify radiographic density limitations for hole-type IQIs. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
T-292 Radiograph Review Form	T-292 was revised to state: The Manufacturer shall be responsible for the preparation of a radiograph review form. As a minimum, the following information shall be provided.	This revision adds rules to clarify that the Manufacturer is ultimately responsible for preparation of the radiographic review form even if this activity is subcontracted. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
T-292 Radiograph Review Form	T-292 was revised to state: *(b)* the information required in T-291, by inclusion of the information on the review form or by reference to an attached radiographic technique details sheet.	This revision adds rules to clarify the intent of requirements that the radiographic technique details must either be attached to or included in the radiographic review form. Revision of this rule does not violate the fundamental safety assumptions

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		stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Appendix V Glossary of Terms for Radiographic Examination	Appendix V – Glossary of Terms for Radiographic Examination was deleted from the 2019 edition.	This revision does not include Appendix V Glossary of Terms for Radiographic Examination. (Note: see Article 1, Appendix I for a complete Glossary of Terms for Nondestructive Examination used in Section V.) Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix VIII Radiography Using Phosphor Imaging Plate	VIII-221.1 – Written Procedure was revised to add the following additional information: *(i)* image scanning parameters (i.e., gain, laser resolution), detailed, as applicable, for material thicknesses across the thickness range *(j)* pixel intensity/gray range (minimum to maximum)	This revision adds rules for information to be included in a written procedure. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix VIII Radiography Using Phosphor Imaging Plate	VIII-221.2 – Procedure Demonstration was revised to state: A demonstration shall be required at the minimum and maximum material thicknesses stated in the procedure. Procedure demonstration details and demonstration block requirements are described in Supplement A of this Appendix.	This revision adds rules for procedure demonstration details and demonstration block requirements. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix VIII Supplement A	VIII-A-210 – Scope states: This Supplement provides the details and requirements for procedure demonstrations in accordance with Mandatory Appendix VIII, VIII-221.2. This Supplement shall be used to demonstrate the ability to produce an acceptable image in accordance with the requirements of the written procedure.	This revision adds rules for details and requirements for procedure demonstrations in accordance with Mandatory Appendix VIII, VIII-221.2. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix IX Radiography Using Digital Detector Systems	IX-210 – Scopes states: This Appendix provides requirements for the use of direct radiography (DR) techniques using digital detector systems (DDSs), where the image is transmitted directly from the detector rather than using an intermediate process for conversion of an analog image to a digital format. This Appendix addresses applications in which the radiation detector, the source of the radiation, and the object being	This revision adds rules for use of direct radiography (DR) techniques using digital detector systems (DDSs), where the image is transmitted directly from the detector rather than using an intermediate process for conversion of an analog image to a digital format. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the

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	radiographed may or may not be in motion during exposure. Article 2 provisions apply unless modified by this Appendix.	2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix IX Supplement A	IX-A-210 – Scope states: This Supplement provides the details and requirements for procedure demonstrations in accordance with Mandatory Appendix IX, IX-221.2. This Supplement shall be used to demonstrate the ability to produce an acceptable image in accordance with the requirements of the written procedure.	This revision adds rules for details and requirements for procedure demonstrations in accordance with Mandatory Appendix IX, IX-221.2. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Subsection A – Nondestructive Methods of Examination **Article 4 – Ultrasonic Examination Methods for Welds**		
T-466 Calibration for Nozzle Side Weld Fusion Zone and/or Adjacent Nozzle Parent Metal	T-466 was inserted after subparagraph T-465 to state: The number of calibration holes used depends upon the requirements for the examination. If only the nozzle side fusion zone is to be examined, then only a single side-drilled hole at the nozzle wall thickness needs to be used.	This revision adds rules for calibration for nozzle side weld fusion zone and/or adjacent nozzle parent metal. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
T-467 Calibration Confirmation (Note: Subparagraph T-466 in the 2007 edition is titled: Calibration Confirmation)	T-467.2– Calibration Checks was revised to state: A calibration check on at least one of the reflectors in the basic calibration block or a check using a simulator shall be performed at the completion of each examination or series of similar examinations, and when examination personnel (except for automated equipment) are changed. The distance range and sensitivity values recorded shall satisfy the requirements T-467.3.	This revision adds rules for calibration confirmation by eliminating the every-4-hour calibration check requirement during the examination. Digital instruments do not exhibit the typical amount of drift associated with the analog equipment. This revision gives users flexibility with today's modern and more dependable digital equipment. If a user has an analog system where experience has shown drift to be significant, an even shorter verification time period for checks should be imposed, such as every 2 hours. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix II Amplitude Control Linearity	II-440 was revised to state: Position an angle beam search unit on a basic calibration block, as shown in Figure I-440 so that the indication from the 1/2*T* side-drilled hole is peaked on the screen. Adjust the sensitivity (gain) as shown in the following table.	This Mandatory Appendix revises amplitude control linearity limits from 4%-16% to ±5% of full screen height. This revision was deemed appropriate based on improvements to UT equipment accuracy. Revision of this rule does not violate the fundamental safety assumptions stated or implied in

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	The Indication Limits % of Full Screen as a function Indication Set at % of Full Screen are: 80% −6 dB 35 to 44% 80% −12 dB 15 to 25% 40% +6 dB 65 to 95% 20% +12 dB 65 to 95%	the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix III Time of Flight Diffraction (TOFD) Technique	III-431.2 – Data Display and Recording was revised to state: The data display shall allow for the viewing of the unrectified A-scan so as to position the start and length of a gate that determines the extent of the A-scan time-base that is recorded. Equipment shall permit storage of all gated A-scans to a magnetic or optical storage medium. Equipment shall provide a sectional view of the weld with a minimum of 64 gray scale levels.	This Mandatory Appendix revises rules for equipment that provides a sectional view of the weld with a minimum of 64 gray scale levels by deleting the color level requirement for the Time-of-Flight Diffraction (TOFD) technique. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix III Time of Flight Diffraction (TOFD) Technique	III-463.3 – Confirmation of Sensitivity was revised to state: Scan the calibration block's SDHs with them centered between the probes, at the reference sensitivity level set in III-463.2. The SDH responses from the required zone shall be a minimum of 6 dB above the grain noise and shall be apparent in the resulting digitized grayscale display.	This Mandatory Appendix revises rules to require confirmation of sensitivity by a minimum signal to noise ratio of 6 dB for side drilled hole (SDH) indications, as well as requiring the SDH images to be visible in the digitized grayscale display for the Time-of-Flight Diffraction (TOFD) technique. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix III Time of Flight Diffraction (TOFD) Technique	III-486 – Flaw Sizing and Interpretation was revised to state: When height of flaw sizing is required, after the system is calibrated per III-463, a free run on the calibration block shall be performed and the depth of the back-wall reflection calculated by the system shall be within 0.04 in. (1 mm) of the actual thickness. For multiple zone examinations where the back wall is not displayed or barely discernible, a side-drilled hole or other known depth reference reflector in the calibration block may be used. See Nonmandatory Appendices L and N of this Article for additional information on flaw sizing and interpretation.	This Mandatory Appendix revises rules to allow alternate reference reflectors to be used to confirm depth accuracy and permit final interpretation only after all adjustments to the displayed data have been made for the Time-of-Flight Diffraction (TOFD) technique. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.

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	Final interpretation shall only be made after all display parameter adjustments (i.e., contrast, brightness, lateral and backwall removal and SAFT processing, etc.) have been completed.	
Mandatory Appendix III Time of Flight Diffraction (TOFD) Technique	III-492 – Examination Record was revised to state: For each examination, the required information in T-492 and the following information shall be recorded: (a) probe center spacing (PCS) (b) data sampling spacing (c) flaw height, if specified (d) the final display processing levels	This Mandatory Appendix revises rules requiring documentation of final display processing levels for the Time-of-Flight Diffraction (TOFD) technique. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix V Phased Array E-Scan and S-Scan Linear Scanning Examination Techniques	V-410 – Scope states: This Mandatory Appendix describes the requirements to be used for phased array E-scan (fixed angle) and S-scan encoded linear scanning examinations using linear array search units.	This Mandatory Appendix adds rules for phased array E-scan and S-scan linear scanning examination techniques. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix VII Ultrasonic Examination Requirements for Workmanship-Based Acceptance Criteria	VII-410 – Scope states: This Mandatory Appendix provides requirements when an automated or semiautomated ultrasonic examination is performed for workmanship-based acceptance criteria.	This Mandatory Appendix adds rules for ultrasonic examination requirements for workmanship-based acceptance criteria. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix VIII Ultrasonic Examination Requirements for Fracture-Mechanics-Based Acceptance Criteria	VIII-410 – Scope states: This Mandatory Appendix provides requirements when an automated or semiautomated ultrasonic examination is performed for fracture-mechanics-based acceptance criteria. When fracture-mechanics-based acceptance criteria are used with the full matrix capture (FMC) ultrasonic technique, Mandatory Appendix XI shall apply.	This Mandatory Appendix adds rules for ultrasonic examination requirements for fracture-mechanics-based acceptance criteria. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix IX Procedure Qualification Requirements for Flaw	IX-410 – Scope states: This Mandatory Appendix provides requirements for the qualification of ultrasonic examination procedures when flaw sizing (i.e., length and through-wall height) and categorization (i.e., surface or subsurface)	This Mandatory Appendix adds rules for procedure qualification requirements for flaw sizing and categorization, Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section V of the ASME BPVC	Equivalent Safety Evaluation
Sizing and Categorization	determination are specified for fracture-mechanics-based acceptance criteria.	Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix X Ultrasonic Examination of High-Density Polyethylene	X-410 – Scope states: This Appendix describes requirements for the examination of butt fusion welds in high density polyethylene (HDPE) pipe using encoded pulse echo, phased array, or time of flight diffraction (TOFD) ultrasonic techniques.	This Mandatory Appendix adds rules for ultrasonic examination of high-density polyethylene. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix XI Full Matrix Capture	XI-410 – Scope states: This Appendix provides the requirements for using the full matrix capture (FMC) ultrasonic technique, in conjunction with data reconstruction techniques, when examinations are performed for fracture-mechanics-based acceptance criteria. A general description of FMC data and data reconstruction techniques is given in Article 4, Nonmandatory Appendix F.	This Mandatory Appendix adds rules for full matrix capture ultrasonic technique. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Nonmandatory Appendix F Examination of Welds Using Full Matrix Capture	F-410 – Scope states: This Appendix contains a description of the processes and technique(s) for the full matrix capture (FMC) ultrasonic (UT) examination technique. An FMC examination consists of data collection and image construction aspects.	This Nonmandatory Appendix adds rules that describe processes and technique(s) for the full matrix capture (FMC) ultrasonic (UT) examination technique. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Nonmandatory Appendix O Time of Flight Diffraction (TOFD) Technique — General Examination Configurations	O-410 – Scope states: This Appendix describes general weld examination configurations for the Time-of-Flight Diffraction (TOFD) technique.	This Nonmandatory Appendix adds rules that describe general weld examination configurations for the Time-of-Flight Diffraction (TOFD) technique. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Nonmandatory Appendix P Phased Array (PAUT) Interpretation	P-410 – Scope states: This Nonmandatory Appendix is to be used as an aid for the interpretation of Phased Array Ultrasonic Testing (PAUT) images. The flaw signal interpretation methodology using PAUT is very similar to that of conventional ultrasonics; however, PAUT has improved imaging capabilities that aid in flaw signal interpretation. This interpretation guide is	This Nonmandatory Appendix provides aid in interpretation of Phased Array Ultrasonic Testing (PAUT) images. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.

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	primarily aimed at using shear wave angle beams on butt welds. Other possibilities include (a) longitudinal waves (b) zero degree scanning (c) complex inspections, e.g., nozzles, fillet welds	
Nonmandatory Appendix Q Example of a Split DAC Curve	Q-410 – Scope states: This Appendix provides an example of a split DAC curve when a single DAC curve, for the required distance range, would have a portion of the DAC fall below 20% of full screen height (FSH). See Figure Q-410.	This Nonmandatory Appendix provides an example of a split distance–amplitude correction (DAC) curve. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Nonmandatory Appendix R Straight Beam Calibration Blocks for Restricted Access Weld Examinations	R-410 – Scope states: This Appendix is to be used as an aid for the fabrication of calibration blocks used for straight beam examinations of welds that cannot be fully examined from two directions using the angle beam technique (e.g., corner and tee joints) per T-472.2.	This Nonmandatory Appendix provides aid in the fabrication of calibration blocks used for straight beam examinations of welds that cannot be fully examined from two directions using the angle beam technique. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Subsection A – Nondestructive Methods of Examination **Article 5 – Ultrasonic Examination Methods for Materials**		
T-534 Calibration Block Requirements	T-534 was revised to state: The material from which the block is fabricated shall be (a) the same product form, (b) the same material specification or equivalent P-Number grouping, and (c) of the same heat treatment as the material being examined. For the purposes of this paragraph, *product form* is defined as wrought or cast, and P-Nos. 1, 3, 4, 5A through 5C, and 15A through 15F materials are considered equivalent. The finish on the scanning surface of the block shall be representative of the scanning surface finish on the material to be examined.	This rule revision clarifies the definition for *product form*. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Appendix III Glossary of Terms for Ultrasonic Examination	Appendix III – Glossary of Terms for Ultrasonic Examination was deleted from the 2019 edition.	The 2021 edition does not include Appendix III – Glossary of Terms for Ultrasonic Examination so an equivalent safety evaluation is not possible. (Note: See Article 1, Appendix I for a

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section V of the ASME BPVC	Equivalent Safety Evaluation
		complete Glossary of Terms for Nondestructive Examination used in Section V.)
Subsection A – Nondestructive Methods of Examination Article 6 – Liquid Penetrant Examination		
T-676.3 Color Contrast Penetrants	T-676.3 was revised to state: Illumination (natural or supplemental white light) of the examination surface is required for the evaluation of indications. The minimum light intensity shall be 100 fc (1 076 lx). The light intensity, natural or supplemental white light source, shall be measured with a white light meter prior to the evaluation of indications or a verified light source shall be used. Verification of light sources is required to be demonstrated only one time, documented, and maintained on file.	This revision adds rules to clarify that the light source for color-contrasted PT, MT and direct visual shall be measured with a white light meter or a verified light source. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Appendix I Glossary of Terms for Liquid Penetrant Examination	Appendix I – Glossary of Terms for Liquid Penetrant Examination was deleted from the 2021 edition.	The 2021 edition does not include Appendix I – Glossary of Terms for Liquid Penetrant so an equivalent safety evaluation is not possible. (Note: See Article 1, Appendix I for a complete Glossary of Terms for Nondestructive Examination used in Section V.)
Subsection A – Nondestructive Methods of Examination Article 7 – Magnetic Particle Examination		
T-762 Lifting Power of Yokes	T-762 was revised to state: *(a)* The magnetizing power of yokes shall be verified prior to use each day the yoke is used. The magnetizing power of yokes shall be verified whenever the yoke has been damaged or repaired.	This revision adds rules to verify the magnetizing power of yokes prior to each day the yoke is used rather than within the past year. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Appendix II Glossary of Terms for Magnetic Particle Examination	Appendix II – Glossary of Terms for Magnetic Particle Examination was deleted from the 2019 edition.	The 2021 edition does not include Appendix II – Glossary of Terms for Magnetic Particle Examination so an equivalent safety evaluation is not possible. (Note: See Article 1, Appendix I for a complete Glossary of Terms for Nondestructive Examination used in Section V.)
Mandatory Appendix IV Qualification of Alternate Wavelength	IV-710 – Scope states:	This Mandatory Appendix adds rules for the methodology to qualify the performance of fluorescent particle examinations using alternate wavelength sources. Addition of this rule does

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Light Sources for Excitation of Fluorescent Particles	This Appendix provides the methodology to qualify the performance of fluorescent particle examinations using alternate wavelength sources.	not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix V Requirements for The Use of Magnetic Rubber Techniques	V-710 – Scope states: This Appendix provides the methodology and equipment requirements applicable for performing magnetic particle examinations using magnetic rubber techniques in place of wet or dry magnetic particles. The principal applications for this technique are (a) limited visual or mechanical accessibility, such as bolt holes (b) coated surfaces (c) complex shapes or poor surface conditions (d) discontinuities that require magnification for detection and interpretation (e) permanent record of the actual inspection	This Mandatory Appendix adds rules for the methodology and equipment requirements applicable for performing magnetic particle examinations using magnetic rubber techniques. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Subsection A – Nondestructive Methods of Examination Article 8 – Eddy Current Examination		
Appendix I Glossary of Terms for Eddy Current Examination	Appendix I – Glossary of Terms for Eddy Current Examination was deleted from the 2021 edition.	The 2021 edition does not include Appendix I – Glossary of Terms for Eddy Current Examination so an equivalent safety evaluation is not possible. (Note: See Article 1, Appendix I for a complete Glossary of Terms for Nondestructive Examination used in Section V.)
Mandatory Appendix VIII Alternative Technique for Eddy Current Examination of Nonferromagnetic Heat Exchanger Tubing, Excluding Nuclear Steam Generator Tubing	VIII-810 – Scope states: This Appendix provides the requirements for bobbin coil, multifrequency, multiparameter, eddy current examination for installed nonferromagnetic heat exchanger tubing, excluding nuclear steam generator tubing, when this Appendix is specified by the referencing Code Section.	This Mandatory Appendix adds rules for bobbin coil, multifrequency, multiparameter, eddy current examinations for installed nonferromagnetic heat exchanger tubing. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix IX Eddy	IX-810 – Scope states: This Appendix provides the requirements for the detection and length sizing of surface-	This Mandatory Appendix adds rules for the detection and length sizing of surface-breaking flaws on ferromagnetic and

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section V of the ASME BPVC	Equivalent Safety Evaluation
Current Array Examination of Ferromagnetic and Nonferromagnetic Materials for the Detection of Surface-Breaking Flaws	breaking flaws on ferromagnetic and nonferromagnetic materials using the eddy current array (ECA) technique.	nonferromagnetic materials using the eddy current array technique. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Subsection A – Nondestructive Methods of Examination Article 10 – Leak Testing		
Mandatory Appendix XI Helium Mass Spectrometer — Helium-Filled-Container Leakage Rate Test	XI-1010 – Scope states: This technique describes the use of a helium mass spectrometer leak detector (HMSLD) to detect and measure minute traces of helium gas from a helium-filled container into an evacuated volume. The evacuated volume may be a test fixture, test device, or permanent feature of the structure being tested.	This Mandatory Appendix adds rules for use of a helium mass spectrometer leak detector to detect and measure minute traces of helium gas from a helium-filled container into an evacuated volume. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Subsection A – Nondestructive Methods of Examination Article 11 – Acoustic Emission Examination of Fiber-Reinforced Plastic Vessels		
Mandatory Appendix III Glossary of Terms for Acoustic Emission Examination of Fiber-Reinforced Plastic Vessels	Mandatory Appendix III – Glossary of Terms for Acoustic Emission Examination of Fiber-Reinforced Plastic Vessels was deleted from the 2019 edition.	The 2021 edition does not include Mandatory Appendix III – Glossary of Terms for Acoustic Emission Examination of Fiber-Reinforced Plastic Vessels so an equivalent safety evaluation is not possible. (Note: See Article 1, Appendix I for a complete Glossary of Terms for Nondestructive Examination used in Section V.)
Subsection A – Nondestructive Methods of Examination Article 13 – Continuous Acoustic Emission Monitoring of Pressure Boundary Components		
Mandatory Appendix VII Glossary of Terms for Acoustic Emission Examination	Mandatory Appendix VII – Glossary of Terms for Acoustic Emission Examination was deleted from the 2019 edition.	The 2021 edition does not include Mandatory Appendix VII – Glossary of Terms for Acoustic Emission Examination so an equivalent safety evaluation is not possible. (Note: See Article 1, Appendix I for a complete Glossary of Terms for Nondestructive Examination used in Section V.)

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section V of the ASME BPVC	Equivalent Safety Evaluation
Subsection A – Nondestructive Methods of Examination **Article 14 – Examination System Qualification**		
Appendix I — Glossary of Terms for Examination System Qualification	Mandatory Appendix I – Glossary of Terms for Examination System Qualification was deleted from the 2019 edition.	The 2021 edition does not include Mandatory Appendix I – Glossary of Terms for Examination System Qualification so an equivalent safety evaluation is not possible. (Note: See Article 1, Appendix I for a complete Glossary of Terms for Nondestructive Examination used in Section V.)
Mandatory Appendix II UT Performance Demonstration Criteria	II-1410 – Scope was revised to state: This Mandatory Appendix provides requirements for three levels of performance demonstration for ultrasonic examination procedures, equipment, and personnel used to detect and size flaws in welds and components for Construction Code applications. Refer to T-1410 regarding specific requirements of the referencing Code Section.	This Mandatory Appendix adds rules for detecting and sizing flaws in both welds and components for Construction Code applications. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix II UT Performance Demonstration Criteria	II-1420 – General was revised to state: Performance demonstration requirements apply to all personnel who detect, record, or interpret indications, or size flaws. Any procedure qualified in accordance with this Appendix is acceptable. Alternatively, the requirements of Section XI, Appendix VIII, may be used.	This Mandatory Appendix adds rules to permit use of requirements in Section XI – Rules for In-service Inspection of Nuclear Power Plant Components, Appendix VIII – Performance Demonstration for Ultrasonic Examination Systems. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix II UT Performance Demonstration Criteria	II-1434.1 – Low Level was revised to state: Qualification blocks shall be fabricated similar to a calibration block in accordance with Article 4, T-434, or Article 5.	This Mandatory Appendix adds rules to permit use of qualification blocks that are fabricated similar to calibration blocks that are in accordance with either Article 4, T-434, or Article 5. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix II UT Performance Demonstration Criteria	II-1434.2 – Intermediate Level was revised to state: *(c)* For blocks over 4 in. (100 mm) thick, the blocks shall include flaws having a size no greater than a flaw acceptable to Table II-1434-1 or Table II-1434-2 for the thickness being	This Mandatory Appendix adds rules for acceptable flaw size for qualification blocks that are over 4 in. (100 mm) thick. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section V of the ASME BPVC	Equivalent Safety Evaluation
	qualified. Figure II-1434 identifies dimensioning of surface and subsurface flaws.	Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix II UT Performance Demonstration Criteria	II-1434.3 – High Level was revised to delete the following statement from the 2007 edition: Alternatively, the requirements of Section XI, Appendix VIII, may be used.	This revision deletes the following statement from the 2007 edition: Alternatively, the requirements of Section XI, Appendix VIII, may be used. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix II UT Performance Demonstration Criteria	II-1450 – Conduct of Qualification Demonstration was revised by deleting *(k)* blind or non-blind testing methods from the list of essential variables.	This revision deletes blind or non-blind testing methods from the list of essential variables for qualification demonstration. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section V of the ASME BPVC and therefore provide equivalent safety.

Table 9.7 Evaluation of equivalent safety for rules and requirements revised or added to the 2021 edition of Section VIII, Division 1 of the ASME BPVC

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Evaluation
U-2 General	U-2*(b)(1)* was revised to state: *(b)(1)* The Manufacturer of any vessel or part to be marked with the Certification Mark has the responsibility of complying with all of the applicable requirements of this Division and, through proper certification, of assuring that all work done by others also complies. The vessel Manufacturer or, when applicable, the part Manufacturer is responsible for the preparation and accuracy of design calculations to show compliance with the rules of this Division, and his signature on the Manufacturer's Data Report Form shall be considered as certification that this has been done. The vessel or part Manufacturer shall have available for the Inspector's review the applicable design calculations. See 10-5 and 10-15*(d)*.	This revision clarifies Manufacturer responsibilities for preparation and accuracy of design calculations to show compliance with the rules of this Division. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety
U-2 General (See Note 1 at the end of Table 9.4 of this report)	U-2*(g)* was revised to state: *(1)* Where design rules do not exist in this Division, one of the following three methods shall be used: *(-a)* Mandatory Appendix 46. *(-b)* proof test in accordance with UG-101. *(-c)* other recognized and generally accepted methods, such as those found in other ASME, EN, ISO, national, and industry standards or codes. This option shall provide details of design consistent with the allowable stress criteria provided in UG-23. *(2)* The provisions of this paragraph shall not be used to justify the use of materials, joining processes (fabrication), examination, inspection, testing, certification, and overpressure protection methods other than those allowed by this Division.	This revision permits use of other design rules including recognized and generally accepted methods, such as those found in other ASME, EN, ISO, national, and industry standards or codes where design rules do not exist in Division 1. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
U-4 Units of Measurement	U-4 states: *(a)* U.S. Customary, SI, or any local customary units may be used to demonstrate compliance with requirements of this edition related to materials, fabrication, examination, inspection, testing, certification, and overpressure protection.	This redesignation of Table 33-1 in the 2007 edition to Table U-4-1 in the 2021 edition does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Evaluation
U-5 Tolerances	U-5 states: The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are considered nominal, and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practices as determined by the designer.	This addition of general requirement in U-5, which was added to the 2010 edition, does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety
UG-6 Forgings	UG-6*(c)* was added to state: *(c)* Forgings certified to SA-105, SA-181, SA-182, SA-350, SA-403, and SA-420 may be used as tubesheets and hollow cylindrical forgings for pressure vessel shells that otherwise meet all the rules of this Division, provided that the following additional requirements are met:	This addition of general requirement permits use of forgings certified to SA-105, SA-181, SA-182, SA-350, SA-403, and SA-420 provided additional requirements are met. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety
UG-11 Prefabricated or Preformed Pressure Parts Furnished Without a Certification Mark	UG-11 was revised for clarification to state: *(a)* Parts furnished under the provisions of *(b)*, *(c)*, and *(d)* need not be manufactured by a Certificate Holder. However, the Manufacturer of the completed vessel or Certification Mark–stamped part shall ensure that parts furnished under the provisions of *(b)*, *(c)*, *(d)*, and *(e)* meet all of the applicable Code requirements such as UCS-79*(d)*, UNF-79*(a)*, UHA-44*(a)*, and UHT-79*(a)*.	This revision ensures controls are in place to satisfy Code requirements. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UG-14 Rods and Bars	UG-14 was revised to state: *(b)* Pressure parts such as hollow cylindrically shaped parts, heads, caps, flanges, elbows, return bends, tees, and header tees may be machined directly from rod or bar as provided in *(1)* through *(4)* below.	This revision permits use of hollow cylindrically shaped parts and heads or caps to be machined from rod or bar, with no restrictions on the material manufacturing method for making the rod or bar. However, limits are placed on sizes of components made from rod and bar to better control through-thickness properties. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UG-16 General	UG-16 was revised to state: *(a)* The design of pressure vessels and vessel parts shall conform to the general design requirements in the following paragraphs and in addition to the specific requirements for Design given in the applicable Parts of Subsections B and C as an alternative, the design rules of Mandatory Appendix 46 may be used.	This revision to general design requirements allows the option to use Section VIII, Division 2 design by rule and design by analysis rules (incorporation of Code Case 2695). Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Evaluation
UG-16 General	UG-16 was revised to state: *(b)(5)(-d)* the minimum thickness used shall not be less than that calculated by the formulas given in UG 27 or 1-1 and in no case less than 0.022 in. (0.5 mm).	This revision provides an exemption from the 1/16 inch [1.5 mm] minimum thickness rule for tubes in air cooled and cooling tower heat exchangers in UG-16*(b)(5)*. When this exemption was added to Section VIII, Division 1, a 500 psi [3.5 MPa] design pressure limit was imposed. This design pressure limit was a carryover from when this rule was originally published as a Code Case. Since there is no technical justification for this limit, the committee removed the 500 psi [3.5 MPa] limit from this paragraph and enabling Code Case 2626 was also approved. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UG-27 Thickness of Shells Under Internal Pressure	UG-27 was revised to state: *(a)* The minimum required thickness of shells under internal pressure shall not be less than that computed by the following formulas, except as permitted by Mandatory Appendix 1 or Mandatory Appendix 32. In addition, provision shall be made for any of the loadings listed in UG-22 – Loadings, when such loadings are expected. The provided thickness of the shells shall also meet the requirements of UG-16, except as permitted in Mandatory Appendix 32. Note: Formulas in terms of the outside radius and for thicknesses and pressures beyond the limits fixed in this paragraph are given in 1-1 to 1-3.	This rule revision allows the use of the alternative thick shell equation given in Appendix 1, 1-2 in lieu of the thickness equation given in UG-27*(c)(1)* for cylindrical shells subject to circumferential stress. Use of this thick-shell equation in Appendix 1 will result in up to a 5% reduction in wall thickness for heavy walled vessels. The equation in Appendix 1 is the same as used in Section VIII, Division 2. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UG-36 Openings in Pressure Vessels	UG-36 was revised to state: *(a)(2*) Openings may be of other shapes than those given in *(1)* above, and all corners shall be provided with a suitable radius. These openings shall be designed in accordance with U-2*(g)*.	This revision requires all corners to be provided with a suitable radius and these openings shall be designed in accordance with U-2*(g)*. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UG-36 Openings in Pressure Vessels	UG-36 was revised to state: *(b)(1*) For openings exceeding these limits, supplemental rules of 1-7 shall be satisfied in addition to the rules of this paragraph.	This revision permits use of the supplemental rules of 1-7 for openings in cylindrical or conical shells that exceed limits in UG-36. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Evaluation
UG-37 Reinforcement Required for Openings in Shells and Formed Heads	UG-37 was revised to state: *(h)* Segmental reinforcing elements are allowed, provided the individual segments are joined by full penetration butt welds. These butt welds shall comply with all the applicable requirements of Part UW. Each segment of the reinforcing element shall have a vent hole as required by *(g)*. Unless the provisions given below are satisfied, the area A_5 as defined in Figure UG-37.1 shall be multiplied by 0.75. The area A_5 does not require any reduction if one of the following is satisfied: *(1)* Each butt weld is radiographed or ultrasonically examined to confirm full penetration, or *(2)* For openings in cylinders, the weld is oriented at least 45 deg from the longitudinal axis of the cylinder.	This revision allows segmental reinforcing elements provided the individual segments are joined by full penetration butt welds. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section I of the ASME BPVC and therefore provide equivalent safety. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UG-44 Flanges and Pipe Fittings	UG-44*(b)* was added to state: *(b)* External loads (forces and bending moments) may be evaluated for flanged joints with welding neck flanges chosen in accordance with ASME B16.5, ASME B16.47, and ASME B16.5/ ASME B16.47, using the following requirements:	This additional rule clarifies that superimposed static or dynamic reactions must be considered in supporting calculations to the standard ratings for B16.5 and B16.47 flanges. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UG-80 Permissible Out-of-Roundness of Cylindrical, Conical, and Spherical Shells	UG-80*(a)(10)* and *(a)(11)* in the 2007 edition were deleted and UG-80*(c)* was added to state: *(c)* Vessels and components fabricated of pipe or tube under internal or external pressure may have permissible variations in diameter (measured outside) in accordance with those permitted under the specification covering its manufacture.	These rule changes allow shells of completed pressure vessels to operate under external pressure to be fabricated from pipe and tube product forms. Changes to these rules do not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UG-84 Charpy Impact Tests	UG-84*(g)(2)* was revised to add a last sentence to state: The notch shall be cut approximately normal to the material surface in such a manner as to include as much heat-affected zone material as possible in the resulting fracture. Where the material thickness permits, the axis of the notch may be inclined to allow the root of the notch to align parallel to the fusion line.	This revision adds requirements for each set of heat-affected zone weld impact test specimens to Charpy impact test rules. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UG-84 Charpy Impact Tests	UG-84*(h)(2)* was revised to state: Welding procedure impact tests shall be made when required by UCS-67, UHT-82, or UHA-51. For vessels constructed to the rules of Part UCS, the	This revision requires that the test plate materials heat treated condition be recorded on the Procedure Qualification Record (PQR) and Welding Procedure Specification (WPS). Revision of this rule does not violate the fundamental safety assumptions

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Evaluation
	test plate material shall satisfy all of the following requirements relative to the material to be used in production: *(-a)* be of the same P-Number and Group Number; *(-b)* be in the same heat-treated condition, and this heat-treated condition shall be noted on the PQR and WPS used for construction; and *(-c)* meet the minimum notch toughness requirements of *(c)(4)* for the thickest material of the range of base material qualified by the procedure (see Figure UG-84.1).	stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UG-90 General	UG-90 was revised to state: *(c)(2)* When mass production of pressure vessels makes it impracticable for the Inspector to personally perform each of his required duties, the Manufacturer, in collaboration with the Inspector, shall prepare an inspection and quality control procedure setting forth, in complete detail, the method by which the requirements of this Division will be maintained. This procedure shall be developed, accepted, and implemented in accordance with Mandatory Appendix 35.	This revision includes alterative rules for inspection of mass-produced pressure vessels. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UG-99 Standard Hydrostatic Test	UG-99 was revised to state: *(b)* Hydrostatic testing rules specified in Paragraph UG-99*(b)* in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC state that the minimum hydrostatic test pressure, P_T, is equal to or greater than 1.3 MAWP times the LSR for the materials of which the pressure vessel is constructed. These rules state that the minimum hydrostatic test pressure shall be calculated using the following equation. $$P_T = 1.3\ \text{MAWP}\left(\frac{S_T}{S}\right)$$ However, Paragraph UG-99*(b)* in the 2021 edition of Section VIII, Division 1 of the ASME BPVC provides additional considerations that could affect the magnitude of the minimum hydrostatic test pressure. These additional considerations include the following. • Bolting shall not be included in the determination of the LSR, except when 1.3 times the LSR multiplied by the	This revision requires additional considerations that could affect the magnitude of the minimum hydrostatic test pressure. These additional considerations include the following. • Bolting shall not be included in the determination of the LSR, except when 1.3 times the LSR multiplied by the allowable stress of the bolt at its design temperature exceeds 90% of the bolt material specified minimum yield strength at the test temperature. • The hydrostatic test pressure reading shall be adjusted to account for any static head conditions depending on the difference in elevation between the chamber being tested and the pressure gauge. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Evaluation
	allowable stress of the bolt at its design temperature exceeds 90% of the bolt material specified minimum yield strength at the test temperature. • The hydrostatic test pressure reading shall be adjusted to account for any static head conditions depending on the difference in elevation between the chamber being tested and the pressure gauge.	
UG-99 Standard Hydrostatic Test	UG-99*(f)* was revised and *(f)(1)* and *(f)(2)* were added to state: *(f)(1)* an internal hydrostatic pressure test in accordance with UG-99, or a pneumatic pressure test in accordance with UG-100. The applied test pressure shall be not less than 1.3 times the specified external design pressure; or *(f)(2)* a vacuum test conducted at the lowest value of specified absolute internal design pressure. In conjunction with the vacuum test, a leak test shall be performed following a written procedure complying with the applicable technical requirements of Section V, Article 10 for the leak test method and technique specified by the user. Leak testing personnel shall be qualified and certified as required by Section V, Article 1, T-120(e).	This revision requires that although the value of the hydrostatic test pressure is not only a multiple of the MAWP stamped on the nameplate, it also considers all of the materials which make up the pressure vessel and more specifically the ratio of the material allowable stress at its test temperature to the allowable stress value at its design temperature (stress ratio). The lowest stress ratio (LSR) is then multiplied times the MAWP and the test multiplier (1.3 for a hydrostatic test per UG-99) to determine the minimum test pressure. The change that took place in the 2010 Edition was to eliminate bolting from consideration as material in the determination of the LSR. This change was made since the allowable stress for many commonly used carbon steel and low alloy bolting materials (such as SA-193 Grade B7) does not change at temperatures less than 750°F, whereas the allowable stress does change for most plate and forging materials. The net result is that for many vessels with carbon and low alloy steel bolting, the bolting controls the test pressure and results in a test pressure that is lower than one that would be based on the plate and forging materials in the vessel. This means that the components fabricated from plate and forgings would not achieve the desired stress level during the hydrostatic test relative to its allowable stress at the design temperature. There is one exception concerning consideration of bolting in the determination of the LSR. If 1.3 times the LSR multiplied by the allowable stress of the bolt at its design temperature exceeds 90% of the bolt material specified minimum yield strength at the test temperature, then the bolting stress ratio must be considered in the determination of LSR. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Evaluation
		Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UG-99 Standard Hydrostatic Test	UG-99*(k) Painting and Coating* was revised to state: *(1)* Unless permitted by the user or his designated agent, pressure-retaining welds of vessels shall not be painted or otherwise coated either internally or externally prior to the pressure test. [See UCI-99*(b)* and UCD-99*(b)*.] *(2)* When painting or coating prior to the hydrostatic test is permitted, or when internal nonmetallic linings are to be applied, the pressure-retaining welds shall first be leak tested in accordance with Section V, Article 10. Such a test may be waived with the approval of the user or his designated agent. *(3)* Vessels for lethal service [see UW-2*(a)*] *(-a)* shall not be painted or coated either internally or externally prior to the hydrostatic pressure test *(-b)* shall not be internally lined by mechanical or welded attachments prior to the hydrostatic pressure test unless the requirements of UCL-51 are followed. *(4)* The requirements given in *(1)* and *(2)* do not apply to glass-lined vessels; see 27-4.	This revision adds painting and coating requirements for pressure vessels subjected to standard hydrostatic testing. These requirements address issues associated with painting, coating, and lining of pressure vessel surfaces that may mask leaks that would otherwise have been detected during the pressure test. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UG-99 Standard Hydrostatic Test	UG-99*(l)* was added to state: Custom-designed flange assemblies, including modified standard flange assemblies where additional calculations are required, within the geometric scope of this Division (see Mandatory Appendix 2 and UG-34) shall be tested with gaskets and bolting that meet the following requirements:	This rule adds pressure testing requirements for custom-designed flange assemblies. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UG-100 Pneumatic Test	UG-100 was revised to state that the pneumatic test pressure, P_T, must be established based on the following conditions. • Minimum pneumatic test pressure, P_T, for the materials of which the pressure vessel is constructed is based on rules specified in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. These rules state that the minimum pneumatic test pressure shall be calculated using the following equation.	This revision requires that although the value of the pneumatic test pressure is not only a multiple of the MAWP stamped on the nameplate, it also considers all of the materials which make up the pressure vessel and more specifically the ratio of the material allowable stress at its test temperature to the allowable stress value at its design temperature (stress ratio). The lowest stress ratio (LSR) is then multiplied times the MAWP and the test multiplier (1.3 for a hydrostatic test per UG-99) to

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Evaluation
	$$P_T = 1.1\ \text{MAWP}\left(\frac{S_T}{S}\right)$$ • Maximum P_T is not specified in either the 2007 or 2021 edition of Section VIII, Division 1 of the ASME BPVC. However, rules specified in the 2007 and 2021 editions state that in no case shall the pneumatic test pressure exceed 1.1 times the basis for the calculated test pressure as defined in Mandatory Appendix 3-2. The calculated test pressure, P_T, is defined in Mandatory Appendix 3 – Definitions, Paragraph 3-2 in the 2007 and 2021 editions of Section VIII, Division 1 of the ASME BPVC. This definition states that the requirements for determining the test pressure based on calculations are outlined in UG-99*(c)* for the hydrostatic test and in UG-100*(b)* for the pneumatic test. The basis for calculated test pressure in either of these paragraphs is the highest permissible internal pressure as determined by the design formulas, for each element of the vessel using nominal thicknesses with corrosion allowances included and using the allowable stress values given in Section II, Part D, Tables 1A and 1B, as applicable, of the ASME BPVC for the temperature of the test (See Sect. 4.4.1 of the report).	determine the minimum test pressure. The change that took place in the 2010 Edition was to eliminate bolting from consideration as material in the determination of the LSR. This change was made since the allowable stress for many commonly used carbon steel and low alloy bolting materials (such as SA-193 Grade B7) does not change at temperatures less than 750°F, whereas the allowable stress does change for most plate and forging materials. The net result is that for many vessels with carbon and low alloy steel bolting, the bolting controls the test pressure and results in a test pressure that is lower than one that would be based on the plate and forging materials in the vessel. This means that the components fabricated from plate and forgings would not achieve the desired stress level during the hydrostatic test relative to its allowable stress at the design temperature. There is one exception concerning consideration of bolting in the determination of the LSR. If 1.3 times the LSR multiplied by the allowable stress of the bolt at its design temperature exceeds 90% of the bolt material specified minimum yield strength at the test temperature, then the bolting stress ratio must be considered in the determination of LSR. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UG-100 Pneumatic Test	UG-100*(e) Painting and Coating* was revised to state: *(1)* Unless permitted by the user or his designated agent, pressure-retaining welds of vessels shall not be painted or otherwise coated either internally or externally prior to the pneumatic pressure test. *(2)* When painting or coating prior to the pneumatic test is permitted, or when internal nonmetallic linings are to be applied, the pressure-retaining welds shall first be leak tested in accordance with Section V, Article 10. Such a test may be waived with the approval of the user or his designated agent. *(3)* Vessels for lethal service [see UW-2(a)]	This revision adds painting and coating requirements for pressure vessels subjected to pressure testing. These requirements address issues associated with painting, coating, and lining of pressure vessel surfaces that may mask leaks that would otherwise have been detected during the pressure test. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Evaluation
	(-a) shall not be painted or coated either internally or externally prior to the pneumatic pressure test *(-b)* shall not be internally lined by mechanical or welded attachments prior to the pneumatic pressure test unless the requirements of UCL-51 are followed	
UG-100 Pneumatic Test	UG-100*(g)* was added to state: Custom-designed flange assemblies, including modified standard flange assemblies where additional calculations are required, within the geometric scope of this Division (see Mandatory Appendix 2 and UG-34) shall be tested with gaskets and bolting that meet the following requirements:	This rule adds pressure testing requirements for custom-designed flange assemblies. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UG-117 Certificates of Authorization and Certification Marks (See Sect. 1.3 of this report.)	UG-117 was revised to state: *(a)* A Certificate of Authorization to use the Certification Mark with the U, UM, PRT, UV, or UD Designator shown in Figures UG 116, UG 129.1, and UG 129.2 will be granted by the Society pursuant to the provisions of the following paragraphs. *(b) Application for Certificate of Authorization* was revised to state: Any organization desiring a Certificate of Authorization shall apply to ASME in accordance with the certification process of ASME CA-1.	This revision removes conformity assessment requirements from Section VIII, Division 1 because ASME formed a standards committee (Committee on Conformity Assessment Requirements (CAR) and given it the responsibility for conformity assessment requirements in a new documents ASME CA-1 titled: *Conformity Assessment Requirements*.
UG-118 Methods of Marking	UG-118*(a)* was revised to state: The required marking shall be applied to the vessel by one of the following methods: (*1*) nameplate as provided in UG-119 (*2*) stamped directly on the vessel under the following conditions: (3) electrochemically etched, including the Certification Mark, directly on the vessel *un*der the following conditions: Figure UG-118 references PTB-4 for sample nameplate markings.	This revision adds rules to allow electrochemically etched as one of the methods permitted for marking a pressure vessel. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UG-120 Data Reports	UG-120 was revised to state: *(a)* A Data Report shall be filled out on Form U-1, U-1A, or U-1P by the Manufacturer and shall be signed by the Manufacturer and the Inspector for each pressure vessel marked with the Certification Mark with the U Designator.	This revision adds Form U-1P Manufacturer's Data Report for Plate Heat Exchangers to the list of required data reports. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Evaluation
UG-150 General Requirements	UG-150 states: *(a)* UG-150 through UG-155 provide the acceptable methods and requirements for overpressure protection for pressure vessels constructed to the requirements of this Division. Acceptable methods include pressure relief devices, open flow paths, and overpressure protection by system design. Paragraph UG-150 specifies the type, quantity and settings of acceptable pressure relief devices and relieving capacity requirements including maximum allowed relieving pressures.	This revision defines acceptable methods and requirements for overpressure protection that include pressure relief devices, open flow paths, and overpressure protection by system design. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UG-153 Overpressure Limits	UG-150 was revised to state: *(a)* Other than unfired steam boilers, when a pressure relief device is provided, it shall prevent the pressure from rising more than 10% or 3 psi (20 kPa), whichever is greater, above the maximum allowable working pressure, except as permitted in (1) and (2) and UG 54*(c)*.	This rule revision requires pressure relief device on other that unfired stream boilers that prevent the pressure from rising more than 10% or 3 psi (20 kPa), whichever is greater, above the maximum allowable working pressure. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
All Section VIII, Division 1 pressure relief device requirements have been transferred from UG-125 through UG-140 to Section XIII in the 2021 edition of the ASME BPVC.	The 2021 edition of this Division adopts the new ASME BPVC Section XIII, Rules for Overpressure Protection. All Section VIII, Division 1 pressure relief device requirements have been transferred from UG-125 through UG-140 to Section XIII, and the remaining Section VIII, Division 1 overpressure protection requirements have been restructured within the new UG-150 through UG-156.	This revision was necessary because the 2021 edition of Section VIII, Division 1 adopts the new ASME BPVC Section XIII – Rules for Overpressure Protection. Table PP-1-1 in Nonmandatory Appendix PP – Guide to the Relocation of Overpressure Protection Requirements lists the new locations for all requirements formerly located in UG 125 through UG-140.
UW-2 Service Restrictions	UW-2 was revised to state: *(c)* Unfired steam boilers with design pressures exceeding 50 psi (343 kPa) shall satisfy all of the following requirements: *(1)* All joints of Category A (see UW-3) shall be in accordance with Type No. (1) of Table UW-12, and all joints in Category B shall be in accordance with Type No. (1) or No. (2) of Table UW-12. *(2)* All butt-welded joints shall be fully radiographed except under the provisions of UW-11(a)(4) and except for ERW pipe weld seams. When using ERW pipe as the shell of an unfired steam boiler, its thickness shall not exceed ½ in.	This revision adds rule for ERW pipe such that: when ERW pipe is used as a shell for an unfired steam boiler, its thickness shall not exceed 0.5 in. (13 mm), its diameter shall not exceed 24 in. (DN 600), and the ERW weld shall be completed using high-frequency (HFI) welding. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Evaluation
	(13 mm), its diameter shall not exceed 24 in. (DN 600), and the ERW weld shall be completed using high frequency (HFI) welding. *(3)* When fabricated of carbon or low-alloy steel, such vessels shall be postweld heat treated. *(4)* See also U-1*(g)(1)*, UG-16*(b)*, and UG-125*(b)*.	
UW-5 General	UW-5*(e)* was added and *(f)* was designated to state: *(e)* Welding of SA-841 by the electroslag or electrogas welding process is prohibited. *(f)* Materials joined by the inertia and continuous drive friction welding processes shall be limited to materials assigned P-Numbers in Section IX and shall not include rimmed or semikilled steel.	This revision adds rule for welding of SA-841 by incorporation of Case 2130-4, that permits use of SA-841 Grade A, Class 1 and Grade B, Class 2 plates in Section VIII, Division 1 construction. A restriction on welding this material by electroslag or electrogas process was added to UW-5*(e)*, and the original UW-5*(e)* paragraph renumbered to UW-5*(f)*. A reference to UW-5*(e)* was also added to paragraphs UW-27*(e)* and UW-27*(f)*. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UW-20 Tube-to-Tubesheet Welds	UW-20.7 Clad Tubesheets was added to provides rules for clad tubesheets when the tubes are to be strength welded to the cladding.	This change adds rule for integral clad tubesheets that must meet the shear strength requirements of SA-263 and the ultrasonic examination requirements of SA-263, Quality Level Class 1 when the tubes are to be full or partial strength welded to the cladding of integral clad tubesheets. These requirements would apply to integral clad tubesheets made up of any combination of clad and based materials, not just those covered by SA-263. The shear strength test and ultrasonic examination are not required for weld metal overlay clad tubesheets. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UW-51 Radiographic Examination of Welded Joints	UW-51 was revised to state: *(a)(2)* Demonstration of acceptable density on radiographic films and the ability to see the prescribed image quality indicator (IQI) image and the specified hole or the designated wire of a wire IQI shall be considered satisfactory evidence of compliance with Section V, Article 2.	This revision adds rules for evidence of compliance with Section V, Article 2 requirements for radiographic examination of welded joints. This rule change brings Section VIII, Division 1 into alignment with changes already adopted in Section V and Section I. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the

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		2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UW-53 Ultrasonic Examination of Welded Joints	UW-53 was added to state: *(b)* Ultrasonic examination of welds per UW-51*(a)(4)* shall be performed and evaluated in accordance with the requirements of Section VIII, Division 2, 7.5.5.	This revision adds rules for ultrasonic examination of welds in accordance with the requirements of Section VIII, Division 2, 7.5.5. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UW-54 Qualification of Nondestructive Examination Personnel	UW-54 states: Personnel performing nondestructive examinations in accordance with UW-51, UW-52, or UW-53 shall be qualified and certified in accordance with the requirements of Section V, Article 1, T-120*(e)*, T-120*(f)*, T-120*(g)*, T-120*(i)*, T-120*(j)*, or T-120*(k)*, as applicable.	This revision adds rules to qualification of nondestructive examination personnel. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UB-30 General	UB-30 was revised to state: *(d)* The Manufacturer (Certificate Holder) may engage individuals by contract or agreement for their services as brazers at the shop location shown on the Certificate of Authorization and at field sites (if allowed by the Certificate of Authorization) for the construction of pressure vessels or vessel parts, provided all the following conditions are met:	This revision updates rules to tighter requirements for subcontracted brazers were revised to align with requirements for subcontracted welders. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UCS-56 Requirements for Postweld Heat Treatment	UCS-56 was revised to state: *(a)* Except as otherwise specifically provided in the notes to Tables UCS-56-1 through UCS-56-11 and Table UCS-56.1, all welds in pressure vessels or pressure vessel parts shall be given a postweld heat treatment at a temperature not less than specified in those Tables when the nominal thickness, as defined in UW-40*(f)*, including corrosion allowance, exceeds the limits in those Tables. Tables UCS-56-1 through UCS-56-11 includes postweld treatment requirements for P-No. 1, 3, 4, 5A, 5B, 5C, 9A, 9B, 10A, 10B, 10C, and 15E carbon and low alloy steels.	This revision adds creep-strength-enhanced ferritic steels (P-No. 15E materials) to the list of other carbon and low alloy steels that may require postweld heat treatment. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UCS-79 Forming Pressure Parts	UCS-79 was revised to state: *(d)* Except as addressed in *(e)* and for materials exempted below, the cold-formed areas of vessel shell sections, heads, and other pressure parts shall be heat treated if the resulting extreme fiber elongation determined in accordance with Table UG-79-1 exceeds 5% from the supplied	This revision adds: 1. alternative heating and cooling rates and hold times that may be applied to formed pipe and tube having a nominal thickness of 1/4 in. (6 mm) or less when the heat treatment

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	condition. Heat treatment shall be applied in accordance with UCS-56, except that alternative heating and cooling rates and hold times may be applied to formed pipe and tube having a nominal thickness of 1/4 in. (6 mm) or less when the heat treatment method is demonstrated to achieve a thorough heating of the pipe or tube.	method is demonstrated to achieve a thorough heating of the pipe or tube. 2. reference to Table UG-79-1 which prescribes equations for calculating forming strain that apply to all pressure parts and not just heads and shells. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UW-51 Radiographic Examination of Welded Joints	UW-51 was revised to state: *(a)(2)* Demonstration of acceptable density on radiographic films and the ability to see the prescribed image quality indicator (IQI) image and the specified hole or the designated wire of a wire IQI shall be considered satisfactory evidence of compliance with Section V, Article 2.	This revision adds rules for evidence of compliance with Section V, Article 2 requirements for radiographic examination of welded joints. This rule change brings Section VIII, Division 1 into alignment with changes already adopted in Section V and Section I. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UW-53 Ultrasonic Examination of Welded Joints	UW-53 was added to state: *(b)* Ultrasonic examination of welds per UW-51(a)(4) shall be performed and evaluated in accordance with the requirements of Section VIII, Division 2, 7.5.5.	This revision adds rules for ultrasonic examination of welds in accordance with the requirements of Section VIII, Division 2, 7.5.5. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UW-54 Qualification of Nondestructive Examination Personnel	UW-54 states: Personnel performing nondestructive examinations in accordance with UW-51, UW-52, or UW-53 shall be qualified and certified in accordance with the requirements of Section V, Article 1, T-120*(e)*, T-120*(f),* T-120*(g)*, T-120*(i)*, T-120*(j)*, or T-120*(k)*, as applicable.	This revision adds rules to qualification of nondestructive examination personnel. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UB-30 General	UB-30 was revised to state: *(d)* The Manufacturer (Certificate Holder) may engage individuals by contract or agreement for their services as brazers at the shop location shown on the Certificate of Authorization and at field sites (if allowed by the Certificate of Authorization) for the construction of pressure vessels or vessel parts, provided all the following conditions are met:	This revision updates rules to tighter requirements for subcontracted brazers were revised to align with requirements for subcontracted welders. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.

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UCS-56 Requirements for Postweld Heat Treatment	UCS-56 was revised to state: *(a)* Except as otherwise specifically provided in the notes to Tables UCS-56-1 through UCS-56-11 and Table UCS-56.1, all welds in pressure vessels or pressure vessel parts shall be given a postweld heat treatment at a temperature not less than specified in those Tables when the nominal thickness, as defined in UW-40*(f)*, including corrosion allowance, exceeds the limits in those Tables. Tables UCS-56-1 through UCS-56-11 includes postweld treatment requirements for P-No. 1, 3, 4, 5A, 5B, 5C, 9A, 9B, 10A, 10B, 10C, and 15E carbon and low alloy steels.	This revision adds creep-strength-enhanced ferritic steels (P-No. 15E materials) to the list of other carbon and low alloy steels that may require postweld heat treatment. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UCS-79 Forming Pressure Parts	UCS-79 was revised to state: *(d)* Except as addressed in *(e)* and for materials exempted below, the cold-formed areas of vessel shell sections, heads, and other pressure parts shall be heat treated if the resulting extreme fiber elongation determined in accordance with Table UG-79-1 exceeds 5% from the supplied condition. Heat treatment shall be applied in accordance with UCS-56, except that alternative heating and cooling rates and hold times may be applied to formed pipe and tube having a nominal thickness of 1/4 in. (6 mm) or less when the heat treatment method is demonstrated to achieve a thorough heating of the pipe or tube.	This revision adds: 1. alternative heating and cooling rates and hold times that may be applied to formed pipe and tube having a nominal thickness of ¼ in. (6 mm) or less when the heat treatment method is demonstrated to achieve a thorough heating of the pipe or tube. 2. reference to Table UG-79-1 which prescribes equations for calculating forming strain that apply to all pressure parts and not just heads and shells. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UNF-79 Requirements for Post fabrication Heat Treatment Due to Straining	UNF-79 was revised to state: *(a)(2)* Forming strains shall be determined by the equations in Table UG-79-1. *(b)* was revised to state: When forming strains cannot be calculated as shown in *(a)* above, the Manufacturer shall have the responsibility to determine the maximum forming strain. For flares, swages, or upsets, heat treatment in accordance with Table UNF-79 shall apply, regardless of the amount of strain. Table UNF-79 was revised to add more materials.	This revision adds: 1. references equations in Table UG-79-1 for determining forming strains; 2. requires mandatory post-fabrication heat treatment for all tube and pipe flares, swages, and upsets that are cold formed and exceed the design temperature limits given in Table UNF-79; and 3. updates Table UNF-79 by adding more materials. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of

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		Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UHA-44 Requirements for Postfabrication Heat Treatment Due to Straining	UHA-44 was revised to state: *(a)(2)* Forming strains shall be determined by the equations in Table UG-79-1. *(b)* was further revised to state: When forming strains cannot be calculated as shown in *(a)* above, the Manufacturer shall have the responsibility to determine the maximum forming strain. For flares, swages, or upsets, heat treatment in accordance with Table UHA-44 shall apply, regardless of the amount of strain. Table UHA-44 was revised to add more materials.	This revision adds: 1. references equations in Table UG-79-1 for determining forming strains; 2. require mandatory post-fabrication heat treatment for all tube and pipe flares, swages, and upsets that are cold formed and exceed the design temperature limits given in Table UHA-44; and 3. updates Table UHA-44 by adding more materials. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UHA-51 Impact Tests	UHA-51 was revised to state: Impact tests, as prescribed in *(a)*, shall be performed on materials listed in Table UHA-23 for all combinations of materials and minimum design metal temperatures (MDMTs) except as exempted in *(d)*, *(e)*, *(f)*, *(g)*, *(h)*, or *(i)*. Impact testing is required for UNS S17400 materials. Impact tests are not required where the maximum obtainable Charpy specimen has a width along the notch less than 0.099 in. (2.5 mm). As an alternative method to impact tests, ASTM E1820 J_{Ic} tests are allowed when the MDMT is colder than −320°F (−196°C). See Figures JJ-1.2-1 through JJ-1.2-5 for flowchart illustrations of impact testing requirements.	This rule change revises and clarifies impact test requirements for minimum design metal temperatures (MDMTs) colder than −320°F (−196°C). Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UHX-8 Tubesheet Effective Bolt Load, W^*	UHX-8 was added. UHX-8.1 Scope states: Table UHX-8.1 provides the tubesheet effective bolt load, W^*, transmitted to the perforated region of the tubesheet for each combination of Configuration and Loading Case. The bolt loads shall be calculated using the appropriate formula from Mandatory Appendix 2 considering the requirements in UHX-4*(b)*. (Note: W^* = tubesheet effective bolt load selected from Table UHX-8.1 for the respective Configuration and Loading Case.)	This change adds rules to determine tubesheet effective bolt loads. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.

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UHX-13.5 Calculation Procedure	UHX-13.5.9 Step 9 states: Perform this step for each loading case. UHX-13.5.10 Step 10 was added to state: Perform this step for each loading case. *(a)* Calculate the axial membrane stress in each different shell section. For shell sections integral with the tubesheet having a different material and/or thickness than the shell, refer to UHX-13.6 for the nomenclature. UHX-3.5.11 Step 11 was redesignated to state: For each loading case, calculate the stresses in the shell and/or channel when integral with the tubesheet (Configurations a, b, and c). UHX-13.5.12 Step 12 was redesignated to state: The design shall be reconsidered by using one or a combination of the following three options:	This revision to the calculation procedure adds rules (Step 10) to limit the heat exchanger shell membrane (tensile and compressive) stresses. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UHX-13 Rules for the Design of Fixed Tubesheets	UHX-13.8.4 Calculation Procedure was revised to state: The calculation procedure given in UHX-13.5 and UHX-13.6, if applicable, shall be performed only for the operating loading cases accounting for the modifications given in *(a)* through *(g)*. Table UHX-13.8.4-1 provides the load combinations required to evaluate the heat exchanger for each operating condition x.	This revision adds Table UHX-13.8.4-1 which provides the load combinations required to evaluate the heat exchanger for each operating condition x. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UHX-14 Rules for The Design of Floating Tubesheets	UHX-14.4*(b)(1) Design Loading Cases* was revised to state: Table UHX-14.4-1 provides the load combinations required to evaluate the heat exchanger for the design condition.	This revision adds Table UHX-14.4-1 which provides the load combinations required to evaluate the heat exchanger for the design condition. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UHX-14 Rules for The Design of Floating Tubesheets	UHX-14.6.4 Calculation Procedure was revised to state: The calculation procedure given in UHX-14.5 shall be performed for the operating loading cases accounting for the modifications in *(a)* through *(e)*. Table UHX-14.6.4-1 provides the load combinations required to evaluate the heat exchanger for each operating condition x.	This revision adds Table UHX-14.6.4-1 provides the load combinations required to evaluate the heat exchanger for each operating condition x. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UHX-14 Rules for The Design of Floating Tubesheets	UHX-14.8 Calculation Procedure for Effect of Plasticity at Tubesheet/Channel or Shell Joint was added. 14.8.1 Scope to states: This procedure describes how to use the rules of UHX-	This revision adds a procedure to UHX-14 that describes for how to use the rules of UHX-14.5 when the effect of plasticity at the shell–tubesheet and/or channel–tubesheet joint is to be

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	14.5 when the effect of plasticity at the shell–tubesheet and/or channel–tubesheet joint is to be considered.	considered. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UHX-20 Examples	UHX-20 was revised to state: See UG-16*(f)*. Paragraph UG-16*(f)* states: Examples showing the application of the design rules of this Division are contained in ASME PTB-4, ASME Section VIII, Division 1, Example Problem Manual.	This addition directs users to UG-16*(f)* for examples showing the application of the design rules of this Division. These examples are contained in ASME PTB-4, ASME Section VIII, Division 1, Example Problem Manual. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
UIG Requirements tor Pressure Vessels Constructed of Impregnated Graphite	UIG was added. UIG-1 Scope states: The rules in Part UIG are applicable to pressure vessels and vessel parts that are constructed of impervious graphite and graphite compounds and shall be used in conjunction with the rules in this Division insofar as these requirements are applicable to graphite materials. Impregnated graphite vessels may not be constructed under the rules of U-1*(j)* or UG-90*(c)(2)*.	This change adds Part UIG permitting the use of impregnated graphite material for the construction of pressure vessels and vessel parts. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 3 Definitions	3-2 Definitions of Terms was revised to add definitions for: Certifying Engineer: an engineer or other technical professional duly accredited and qualified to practice engineering activities as required by the Division. Designer – an individual who is qualified to design pressure vessels in accordance with the rules of this Division by demonstrated knowledge in Code requirements and proficiency in selecting correct design formulas and appropriate values to be used when preparing the design of a pressure vessel.	This revision adds definitions for Certifying Engineer and Designer. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 10 Quality Control System	10-13 Records Retention was revised by adding two documents to the list of records to be maintained by Manufacturer or Assembler: *(b)* The Manufacturer or Assembler shall maintain the documents outlined below for a period of at least 3 yr: *(b)(5)* Pressure parts documentation and certifications *(b)(7)* Welder/Welding Operator Performance Qualification Records for each welder who welded on the vessel	This revision adds two documents to the list of records to be maintained by Manufacturer or Assembler for at least 3 years. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.

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Mandatory Appendix 16 Submittal of Technical Inquiries to the Boiler and Pressure Vessel Committee	Mandatory Appendix 16 was deleted from the 2019 edition.	This revision relocates requirements for Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees from Mandatory Appendix 16 in the 2007 edition to the front matter in the 2021 edition of Section VIII, Division 1 of the ASME BPVC. Relocation of this requirement does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 24 Design Rules for Clamp Connections	24-1*(f)* was revised to state: Clamps designed to the rules of this Appendix shall be provided with a bolt retainer. The retainer shall be designed to hold the clamps together independently in the operating condition in case of failure of the primary bolting.	This revision adds rules intended to recognize other clamp designs, and to permit the use of U-2*(g)* to design these other types of clamps when the rules of Mandatory Appendix 24 do not apply. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 26 Bellows Expansion Joints	26-2 Conditions of Applicability was revised to state: *(e)* These rules are valid for design temperatures (see UG-20) up to the temperatures shown in Table 26-2-1. Above these temperatures, the effects of time-dependent behavior (creep and creep–fatigue interaction) shall be considered in accordance with U-2*(g)*.	This revision adds rules for considering effects of time-dependent behavior (creep and creep–fatigue interaction) for bellows expansion joints. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 26 Bellows Expansion Joints	26-2 Conditions of Applicability was added to state: *(f)* The fatigue equations given in 26-6.6.3.2, 26-7.6.3.2, and 26-8.6.3.2 are valid for austenitic chromium-nickel stainless steels, UNS N066XX and UNS N04400. For other materials, the fatigue evaluation shall meet the requirements of 26-4.2.3.	This revision adds rules for fatigue equations for austenitic chromium-nickel stainless steels and other materials. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 26 Bellows Expansion Joints	26-2 Conditions of Applicability was added to state: *(g)* The length of the cylindrical shell on each side of the bellows shall not be less than $1.8\sqrt{D_s t_s}$. The length shall be taken from the beginning of the end convolution [point A in Figure 26-1-2, sketches (a) and (b)], except that for internally attached toroidal bellows, the length shall be taken from the extremity of the shell [point B in Figure 26-1-2, sketch (b)].	This revision adds rules for the minimum length of cylindrical shells on each side of bellows expansion joints. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 32 Local	32-4 Allowable Locations for Local Thin Areas states: *(a)* For openings meeting UG-36*(c)(3)*, the minimum distance between	This revision prescribes limits on the circumferential extent of the local thin areas (LTA) was changed from $2\sqrt{Rt}$ to $\sqrt{Rt}$,

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Thin Areas in Cylindrical Shells and in Spherical Segments of Shells	the edge of the LTA and the center of the opening shall be equal to or greater than the inside diameter of the opening plus $\sqrt{Rt}$.	which allows greater variability in the size of the LTA, since this limit is no longer tied to the axial length of the LTA. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 33 Standard Units for Use in Equations	Mandatory Appendix 33 was deleted.	This deletion was necessary because the standard units for use in equations was relocated for Mandatory Appendix 33 in the 2007 edition to Table U-4-1 in the 2021 edition of Section VIII, Division 1 of the ASME BPVC.
Mandatory Appendix 35 Rules for Mass Production of Pressure Vessels	Mandatory Appendix 35 was added. 35-2 Scope states: This Appendix provides rules allowing the Manufacturer of mass-produced pressure vessels bearing the U Designator to assume responsibility for carrying out some of the Inspector’s duties normally assigned under UG-90*(c)(1)*, in addition to the responsibilities normally assigned to the Manufacturer in UG-90*(b)*. A mass-production program for pressure vessel fabrication may be implemented when the requirements of this Appendix are met.	This revision prescribes rules in Mandatory Appendix 35 that allows Manufacturers of mass-produced pressure vessels to assume responsibility for carrying out some of the Inspector’s duties. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 36 Standard Test Method for Determining the Flexural Strength of Certified Materials Using Three-Point Loading	Mandatory Appendix 36 was added. 36-1 Scope states: This test method outlines the determination of the flexural strength of Certified Material, as required by UIG-84, using a simple beam in three-point loading at room temperature. This method is restricted to tubes.	This revision prescribes rules in Mandatory Appendix 36 for a standard test method for determining the flexural strength of certified materials using three-point loading. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 37 Standard Test Method for Determining the Tensile Strength of Certified Impregnated Graphite Materials	Mandatory Appendix 37 was added. 37-1 Scope states: This test method outlines the method of determination of the tensile strength of Certified Carbon and Graphite Materials, as required by UIG-84, using cylindrical specimens at designated temperature.	This revision adds standard test method for determining the tensile strength of certified impregnated graphite materials. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 38 Standard	Mandatory Appendix 38 was added. 38-1 Scope states: *(a)* This test method covers the determination of the compressive	This revision adds standard test method for compressive strength of impregnated graphite. Addition of this rule does not

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Test Method for Compressive Strength of Impregnated Graphite	strength of impervious carbon and graphite at room temperature. *(a)* This test method covers the determination of the compressive strength of impervious carbon and graphite at room temperature.	violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 39 Testing the Coefficient of Permeability of Impregnated Graphite	Mandatory Appendix 39 was added. 39-1 Scope and Field of Application states: The vacuum-decay method specified in this standard serves to determine the coefficient of permeability of test specimens made from carbon and graphite materials (solid matter) at room temperature. With this method using air as experimental gas, coefficients of permeability between about 101 and 10−9 in.2/sec can be determined. The coefficient of permeability gives the admittance of gas through solid materials.	This revision adds rules for testing the coefficient of permeability of impregnated graphite. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 40 Thermal Expansion Test Method for Graphite and Impregnated Graphite	Mandatory Appendix 40 was added. 40-1 Scope states: This method shall be used to determine thermal expansion factors for *(a)* characterization of material with the grain direction (W.G.) and against the grain (A.G.) *(b)* thermal or mechanical calculation in material application	This revision adds rules for thermal expansion test method for graphite and impregnated graphite. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 41 Electric Immersion Heater Element Support Plates	Mandatory Appendix 41 was added. 41-1 Scope states: (a) The rules in this Mandatory Appendix cover the design of electric immersion heater element support plates, hereafter referred to as EIH support plates. EIH support plates are gasketed with a mating flange (Figure 41-1-1). (b) The rules of UG-34 and UG-39 are not applicable to EIH support plates constructed in accordance with this Mandatory Appendix.	This revision adds rules for electric immersion heater element support plates. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 42 Diffusion Bonding	Mandatory Appendix 42 was added. 42-1 General states: This Mandatory Appendix establishes the requirements for procedure specifications for diffusion bonding in the construction of microchannel heat exchangers.	This revision adds rules for Diffusion Bonding that incorporate Code Case 2621-1. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 43 Establishing Governing Code Editions and	Mandatory Appendix 43 was added. 43-1 General states: *(a)* After Code revisions are approved by ASME, they may be used beginning with the date of issuance shown on the Code. Except as noted in *(b)* below, revisions become mandatory 6 months after the date of issuance. Code Cases are permissible and may	This revision adds rules for governing editions and code cases of the ASME BPVC. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Evaluation
Cases for Pressure Vessels and Parts	be used beginning with the date of approval by ASME. Only Code Cases that are specifically identified as being applicable to this Section may be used.	
Mandatory Appendix 44 Cold Stretching of Austenitic Stainless Steel Pressure Vessels	Mandatory Appendix 44 was added. 44-1 Scope states: This Mandatory Appendix provides requirements for designing and constructing cold-stretched austenitic stainless-steel vessels.	This revision adds rules for cold stretching of austenitic stainless steel pressure vessels. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 45 Plate Heat Exchangers	Mandatory Appendix 45 was added. 45-1 Scope states: The rules of this Appendix cover the minimum requirements for design, fabrication, assembly, inspection, testing, and documentation of gasketed, semi welded, welded, and brazed plate heat exchangers (PHEs).	This revision adds rules for plate heat exchangers. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 46 Rules for Use of Section VIII, Division 2	Mandatory Appendix 46 was added. 46-1 Scope states: This Appendix is applicable when using Division 2 to establish the thickness and other design details of a component for a Section VIII, Division 1 pressure vessel.	This revision adds rules for use of Section VIII, Division 2. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 47 Requirements for Pressure Vessel Designers	Mandatory Appendix 47 was added. 47-1 Introduction states: *(a)* A designer, engineer, or Certifying Engineer (see 3-2), designated by the Manufacturer, shall be in responsible charge of the design of a pressure vessel that is certified by that Manufacturer. *(b)* The person in responsible charge of design activities shall be experienced as described in the use of this Division. *(c)* The qualifications and experience required of the person in responsible charge of design activities will depend on the design complexity of the pressure vessel and the nature of the individual's experience.	This revision adds requirements for pressure vessels designers, engineers, and Certifying Engineers. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix 48 Vessels with Acrylic Cylindrical Shells	Mandatory Appendix 48 was added. 48-1 Scope and Service Restriction states: *(a)* The metallic components of a vessel containing cast acrylic shells shall meet the requirements of ASME Section VIII, Division 1.	This revision adds rules for pressure vessels with acrylic cylindrical shells. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 1 of the ASME BPVC	Equivalent Safety Evaluation
	(b) This Appendix requires the use of ASME PVHO-1 for the acrylic parts. When requirements from ASME PVHO are referenced, the terminology from ASME PVHO-1 is used.	
Nonmandatory Appendix L Application of Rules for Joint Efficiency in Shells and Heads of Vessels with Welded Joints	L-1.1 Introduction was revised to state: This Appendix provides guidelines for establishing the appropriate joint efficiency for vessels of welded construction. The joint efficiencies are applied in various design formulas which determine either the minimum required design thicknesses of vessel parts or the maximum allowable working pressure for a given thickness. (Note: Nonmandatory Appendix L title was changed from Examples Illustrating the Application of Code Formulas and Rules in the 2007 edition to Application of Rules for Joint Efficiency in Shells and Heads of Vessels with Welded Joints in the 2019 edition.)	This revision refers to ASME PTB-4, ASME Section VIII, Division 1, Example Problem Manual in UG-16*(f)* for examples showing the application of the design rules of this Division. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Nonmandatory Appendix KK Guide for Preparing User's Design Requirements	Nonmandatory Appendix KK was added. KK-1 Introduction states: *(a)* The instructions contained in this Nonmandatory Appendix are to provide general guidance for the User [see U-2*(a)*] in preparing User's Design Requirements as recommended in U-2*(a)*.	This revision includes general guidance for the user in preparing user's design requirements. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Nonmandatory Appendix LL Graphical Representations of $F_{t.min}$ and $F_{t.max}$	Nonmandatory Appendix LL was added. LL-1 Scope states: This Appendix provides graphical and tabular representations for the following coefficients determined from the Kelvin functions used in UHX-13 and UHX-14.	This revision includes curves that are graphical representations of *Ft* min and *Ft* max. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Nonmandatory Appendix MM Alternative Marking and Stamping of Graphite Pressure Vessels	Nonmandatory Appendix MM was added. MM-1 General Requirements states: *(a)* This procedure may be used to apply the Certification Mark to the graphite part.	This revision includes alternative marking and stamping of graphite pressure vessels. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.
Nonmandatory Appendix NN Guidance to the Responsibilities of the User and Designated Agent	Nonmandatory Appendix NN was added. NN-1 Introduction states: This Nonmandatory Appendix provides a directory for locating the specific Code-assigned responsibilities and other considerations assigned to the user or his designated agent as applicable to the pressure vessel under consideration.	This revision includes guidance to the responsibilities of the user and designated agent. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 1 of the ASME BPVC and therefore provide equivalent safety.

Note 1:
Paragraph U-2*(g)* could be the single most important paragraph in Section VIII, Division 1. The reason is that this paragraph provides guidance to the Manufacturer when rules for design or construction are not published in the standard. For example, if the Manufacturer is constructing a vessel subject to wind, snow or seismic loads, equations are not provided within Section VIII, Division 1 to directly calculate the stresses in the vessel due to these loads. But the absence of equations does not mean that one cannot construct and certify a pressure vessel subject to wind, seismic or snow loads, because U-2*(g)* gives the Manufacturer permission to provide details of design and construction which will be as safe as those provided by the rules of this Division. U-2*(g)* is used for most pressure vessels, in many cases unknowingly. For example, any vessel subject to wind or seismic loads, external loads on nozzles from piping, or supported on saddles is demonstrated to comply with Section VIII, Division 1 via U-2*(g)*.

For the past six years, a Task Group reporting to the Section VIII Standards Committee has been working on several items related to U-2*(g)*. For example, the revisions to U-2*(e)*) concerning the Authorized Inspector's responsibilities for review of design calculations published in the 2015 Edition, were developed by the Task Group U-2*(g)*.

With regard to U-2*(g)*, this revision contains a complete rewrite of that paragraph. It now provides the vessel designer an option to use Section VIII, Division 2 Part 4 to design components for a Section VIII, Division 1 vessel. And rules are introduced that now mandate that use of finite element analysis to design a component for which rules are not available must be carried out in accordance with Section VIII, Division 2 Part 5. The following is a further summary of the revisions associated with this item:

(1) Paragraph U-2*(g)* has been completely rewritten. One of the significant changes in the intent of this paragraph concerns expansion of its applicability from just design to all aspects of construction. As a reminder, the Code defines construction to be an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief. It has long been recognized that Section VIII, Division 1 does not provide details for all aspects of design. For example, explicit rules are not provided for consideration of external loads on nozzles, or a vessel subject to wind or seismic loads. But the expansion of the applicability of U-2*(g)* beyond just design recognizes the practical need to have such a rule. It is not possible within a single standard to describe in exacting detail all of the activities that must take place in constructing the vessel. One simple example concerns heat treatment. Today the Code provides an option to locally heat treat a circumferential band of the vessel containing nozzles and other welded attachments. In these rules given in UW-40*(a)(5)* there is a requirement that states: "The portion of the vessel outside of the circumferential soak band shall be protected so that the temperature gradient is not harmful." This is a performance-based rule that would then require careful engineering consideration to satisfy. It is a classic example where "details of construction" are not provided in a prescriptive fashion, and therefore would require the Manufacturer, subject to the acceptance of the Authorized Inspector, to provide the explicit details that will be used in construction to satisfy the safety intent of the Code. This is a significant shift in philosophy of how U-2*(g)* should be applied. But one aspect of U-2*(g)* that has been retained is that when the Code does provide a rule, whether it be design, fabrication, or material related, then this rule must be followed and there is no option to use U-2(*g*) to get around it. This is stated in the last paragraph of U-2(*g*): "The provisions of this paragraph shall not be used to justify the use of materials, joining processes (fabrication), examination, inspection, testing, certification and overpressure protection methods other than those allowed by this Division." Simply stated, a Manufacturer cannot use U-2*(g)* to use a material that has not been adopted by the Code, or a welding process that is not addressed in Section VIII, Division 1 or Section IX or an NDE method that is not addressed in Section VIII, Division 1 or Section V.

(2) Another expansion to U-2*(g)* scope does concern design. In subparagraph U-2*(g)(1)*, it now provides three options (methods) for design when the Code does not provide explicit rules. These options are:

(a) Use the design-by-rule and design-by-analysis rules Section VIII, Division 2 per Mandatory Appendix 46. The intent of this option is that when the Manufacturer intends to carry out a design utilizing a general-purpose finite element program, then this finite element analysis shall satisfy Part 5 of Section VIII, Division 2.

(b) Proof test per UG-101.

(c) Use of other recognize and generally accepted methods, such as those found in other ASME/EN/ISO/ National/Industry Standards or Codes.

Table 9.8 Evaluation of equivalent safety for rules and requirements revised or added to the 2021 edition of Section VIII, Division 2 of the ASME BPVC

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Evaluation
Part 1 – General Requirements		
1.2.1 Overview (See Sect. 2.3 of this report.)	1.2.1.2 was revised to states: Vessels with an internal or external design pressure not exceeding 103 kPa (15 psi) and multichambered vessels of which the design pressure on the common elements does not exceed 103 kPa (15 psi) were not considered when the rules of this Division were developed and are not considered within the scope.	This rule defines exceptions to the scope of the 2021 edition of Section VIII, Division 2 of the ASME BPVC. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
1.2.1 Overview (See Sect. 2.3 of this report.)	1.2.1.3 was revised to state: The rules of this Division may be used for the construction of the following pressure vessels. These vessels shall be designated as either a Class 1 or Class 2 vessel in conformance with the User's Design Specification required in Part 2.	This rule requires a pressure vessel to be designated as either a Class 1 or Class 2 vessel in conformance with the User's Design Specification. The 2017 edition of Section VIII, Division 2 introduced a two-class vessel structure [17]. A Class 1 vessel is designed using the allowable stresses from Section II, Part D, Subpart 1, Table 2A or Table 2B and has a design margin of 3.0 on ultimate tensile strength (UTS). A Class 2 vessel is designed using the allowable stresses from Section II, Part D, Subpart 1, Table 5A or Table 5B and has a design margin of 2.4 on ultimate tensile strength (UTS).
1.4 Units of Measurement	1.4*(c)* was revised to state: For any single equation, all variables shall be expressed in a single system of units. Calculations using any material data published in this Division or Section II, Part D (e.g., allowable stresses, physical properties, external pressure design factor B) shall be carried out in one of the standard units given in Table 1.2 – Standard Units for Use in Equations.	This revised rule specifies standard units for use in equations provided in the 2021 edition of Section VIII, Division 2 or Section II, Part D of the ASME BPVC. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
1.5 Tolerances	1.5 was added to states: The Code does not fully address tolerances. When dimensions, sizes, or other parameters are not specified with tolerances, the values of these parameters are	This rule adds requirements for addressing dimensions, sizes, or other parameters that are not specified with tolerances. Addition of this rule does not violate the fundamental safety

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Evaluation
	considered nominal, and allowable tolerances or local variances may be considered acceptable when based on engineering judgment and standard practices as determined by the designer.	assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
Annex 1-B Definitions	Annex 1-B.2 includes definitions for 20 terms. Definitions for these terms were either revised from the 2007 edition or added to the 2021 edition as follows. 1-B.2.1 Acceptance by the Inspector (Revised) 1-B.2.2 ASME Designated Organization (Revised) 1-B.2.3 ASME Designee (Revised) 1-B.2.4 Certificate of Compliance (Revised) 1-B.2.5 Certificate of Authorization (Added) 1-B.2.6 Certification Mark (Added) 1-B.2.7 Certification Mark Stamp (Added) 1-B.2.8 Certification Designator (Designator) (Added) 1-B.2.9 Certifying Engineer (Added) 1-B.2.10 Class 1 Vessel (Added) 1-B.2.11 Class 2 Vessel (Added) 1-B.2.14 Designer (Added) 1-B.2.19 Material Test Report (Revised)	The 2021 edition either revises or adds definitions in Annex 1-B and redesignates the terms to restore alphabetical order. Definitions for the added terms follow. 1-B.2.5 Certificate of Authorization – a document issued by the Society that authorizes the use of the ASME Certification Mark and appropriate designator for a specified time and for a specified scope of activity. 1-B.2.6 Certification Mark – an ASME symbol identifying a product as meeting Code requirements. 1-B.2.7 Certification Mark Stamp – a metallic stamp issued by the Society for use in impressing the Certification Mark. 1-B.2.8 Certification Designator (Designator) – the symbol used in conjunction with the Certification Mark for the scope of activity described in a Manufacturer's Certificate of Authorization. 1-B.2.9 Certifying Engineer – an engineer or other technically competent professional duly accredited and qualified to practice engineering as required by this Division. 1-B.2.10 Class 1 Vessel – a vessel that is designed using the allowable stresses from Section II, Part D, Subpart 1, Table 2A or Table 2B. 1-B.2.11 Class 2 Vessel – a vessel that is designed using the allowable stresses from Section II, Part D, Subpart 1, Table 5A or Table 5B. 1-B.2.14 Designer – an individual who is qualified to design pressure vessels in accordance with the rules of this Division by demonstrated knowledge in Code requirements and proficiency in selecting correct design formulas and appropriate values to be used when preparing the design of a pressure vessel. Addition of these terms and definitions does not violate the fundamental safety assumptions stated or implied in the 2007

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Evaluation
		edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
Part 2 – Responsibilities and Duties		
2.2.2 Multiple Identical Vessels	2.2.2 was added to 2.2 User Responsibilities to state: A single User's Design Specification may be prepared to support the design of more than one pressure vessel that is to be located in a single, specific jurisdiction provided that the environmental requirements and jurisdictional regulatory authority applied for each installation location are clearly specified and are the same or more conservative than required. 2.2.2.1 Class 1. The User's Design Specification shall be certified by a Certifying Engineer meeting the requirements described in Annex 2-A when the user provides the data required by 2.2.3.1*(f)(1)* and 2.2.3.1*(f)(2)* to perform a fatigue analysis. 2.2.2.2 Class 2. The User's Design Specification shall be certified by a Certifying Engineer in accordance with Annex 2-A.	The two-class vessel structure (i.e., Class 1 and Class 2) was introduced in the 2017 edition of Section VIII, Division 2 of the ASME BPVC [17]. This rule adds requirements to User's Design Specification for Class 1 and Class 2 construction. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
2.2.3 User's Design Specification	2.2.3.1*(f)(4)* – Corrosion Fatigue rules were added to the 2.2.3.1*(f)* Design Fatigue Life requirements. 2.2.3.1*(f)(4)* states: (-a) The design fatigue cycles given by eqs. (3-F.21) and (3-F.22) do not include any allowances for corrosive conditions and may be modified to account for the effects of environment other than ambient air that may cause corrosion or subcritical crack propagation. If corrosion fatigue is anticipated, a factor should be chosen on the basis of experience or testing, by which the calculated design fatigue cycles (fatigue strength) should be reduced to compensate for the corrosion. (-b) When using (3-F.22) an environmental modification factor shall be specified in the User's Design Specification.	This rule adds requirements for corrosion fatigue to the list of requirements for User's Design Specifications (See Sect. 4.1.7.3 of this report). Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Evaluation
	(-c) If due to lack of experience it is not certain that the chosen stresses are low enough, it is advisable that the frequency of inspection be increased until there is sufficient experience to justify the factor used. This need for increased frequency should be stated in the User's Design Specification.	
2.3.3 Manufacturer's Design Report	Paragraphs 2.3.3.1 and 2.3.3.2 were revised as follows. 2.3.3.1 Certification of a Manufacturer's Design Report for Class 1 was revised to state: *(a)* The Manufacturer's Design Report shall be certified by a Certifying Engineer in accordance with Annex 2-B when any of the following are performed: 2.3.3.2 Certification of a Manufacturer's Design Report for Class 2 was revised to state: The Manufacturer's Design Report shall be certified by a Certifying Engineer in accordance with Annex 2-B.	These rules revise requirements for Certification of a Manufacturer's Design Reports for Class 1 and Class 2 construction (See Sect. 2.3 of this report). Revision of these rules does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
2.3.7 Manufacturer's Design Personnel	2.3.7 was revised to state: The Manufacturer has the responsibility of ensuring all personnel performing and/or evaluating design activities are competent in the area of design (see Annexes 2-C and 2-J).	This rule revises requirements for ensuring all personnel performing and evaluating design activities are competent. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
2.3.10 Application of Certification Mark	2.3.10 was added to state: Vessels or parts shall be stamped in accordance with the requirements in Annex 2-F. The procedure to obtain and use a Certification Mark is described in Annex 2-G.	This rule adds requirements for application of certification marks. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
2.4 The Inspector	2.4.1 – Identification of Inspector was revised to state: All references to Inspectors throughout this Division mean the Authorized Inspector as defined in this paragraph. All inspections required by this Division shall be by an Inspector regularly employed by an ASME accredited Authorized Inspection Agency, as defined in ASME QAI-1 – *Qualifications for Authorized Inspection*, or by a company	This rule adds requirements for identification of inspectors (See Sect. 2.3 of this report). Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Evaluation
	that manufacturers pressure vessels exclusively for its own use and not for resale that is defined as a User-Manufacturer. This is the only instance in which an Inspector may be in the employ of the Manufacturer.	
2.4 The Inspector	2.4.2 Inspector Qualification was revised to state: All Inspectors shall have been qualified in accordance with ASME QAI-1 – *Qualifications for Authorized Inspection*.	This rule revises requirements for inspector qualification accordance with ASME QAI-1. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
Annex 2-A Guide for Certifying a User's Design Specification (Normative)	2-A.1 General was revised to state: *(a)* When required in 2.2.1, one or more individuals in responsible charge of the specification of the vessel and the required design conditions shall certify that the User's Design Specification meets the requirements of this Division and any additional requirements needed for adequate design. Such certification requires the signature(s) of one or more Certifying Engineers as described in *(b)*. One or more individuals may sign the documentation based on information they reviewed and the knowledge and belief that the objectives of this Division have been satisfied. *(b)* One or more individuals in responsible charge of the specification of the vessel and the required design conditions shall certify that the User's Design Specification meets the requirements in 2.2.2. Such certification requires the signature(s) of one or more Certifying Engineers with the requisite technical stature and, when applicable, jurisdictional authority to sign such a document. One or more individuals shall sign the documentation based on information they reviewed and the knowledge and belief that the objectives of this Division have been satisfied. In addition, these individuals shall prepare a statement to be affixed to the document attesting to compliance with the applicable requirements of the Code (see 2-A.2.3).	This rule revises requirements for certifying a User's Design Specification. Such certification requires the signature(s) of one or more Certifying Engineers with the requisite technical stature and, when applicable, jurisdictional authority to sign such a document (See Sect. 2.3 of this report). Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
Annex 2-B Guide for Certifying a	Annex 2-B was revised to allow: 2-B.2 Certification of Manufacturer's Design Report by a Certifying Engineer	These rules revise requirements to allow certification of a Manufacturer's Design Report by a Certifying Engineer or a Designer (See Sect. 2.3 of this report). Revision of these

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Evaluation
Manufacturer's Design Report	2-B.3 Certification of a Manufacturer's Design Report by a Designer See Annex 1-B – Definitions for definitions of Certifying Engineer and Designer.	rules does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
Annex 2-G Obtaining and Using Certification Mark Stamps (Normative)	2-G.1 – Certification Mark was revised to state: A Certificate of Authorization to use the Certification Mark with the U2, PRT, or UV Designator shown in Annex 2-F will be granted by ASME pursuant to the provisions of the following paragraphs. Stamps for applying the Certification Mark shall be obtained from ASME. 2-G.2 – Application for Certificate of Authorization was revised to state: Any organization desiring a Certificate of Authorization shall apply to ASME in accordance with the certification process of ASME CA-1. Authorization to use Certification Marks may be granted, renewed, suspended, or withdrawn as specified in ASME CA-1.	This rule revises requirements for application of Certification Mark prescribed in 2.3.10 that states: Vessels or parts shall be stamped in accordance with the requirements in Annex 2-F. The procedure to obtain and use a Certification Mark is described in Annex 2-G. Revision of these rules does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
Annex 2-H Guide to Information Appearing on the Certificate of Authorization	The 2021 edition does not include Annex 2-H.	The 2021 edition rules for application for certificate of authorization are prescribed in Annex 2-G.2 that states: Any organization desiring a Certificate of Authorization shall apply to ASME in accordance with the certification process of ASME CA-1. Authorization to use Certification Marks may be granted, renewed, suspended, or withdrawn as specified in ASME CA-1.
Annex 2-I Establishing Governing Code Editions and Cases for Pressure Vessels and Parts (Normative)	Annex 2-I was added. 2-I.1 – General states: (a) After Code revisions are approved by ASME, they may be used beginning with the date of issuance shown on the Code. Except as noted below, revisions become mandatory six months after the date of issuance. Code Cases are permissible and may be used beginning with the date of approval by ASME. Only Code Cases that are specifically identified as being applicable to this Section may be used.	This rule adds requirements for establishing governing code editions and cases for pressure vessels and parts. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
Annex 2-J Qualifications and Requirements for	Annex 2-J was added. 2-J.1 – Introduction states:	This rule adds requirements for qualifications and requirements for Certifying Engineers and Designers. Addition of this rule does not violate the fundamental safety assumptions

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Evaluation
Certifying Engineers and Designers	*(a)* Persons engaged in design activity shall be competent in the topic of each design activity performed and shall be able to show evidence of this competency as described in 2-J.2. *(b)* When a Certifying Engineer is required by 2.3.3.1 to certify the Manufacturer's Design Report, it is permissible for a Designer to perform the design activity, provided all the following requirements are met: *(1)* The Designer has evidence of competence in the topic of design under consideration. *(2)* The Designer is working under the responsible charge of a Certifying Engineer.	stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
Part 3 – Material Requirements		
3.2.8 Prefabricated or Preformed Pressure Parts Furnished Without a Code Stamp	3.2.8 was revised to state: 3.2.8.1 – General Requirements *(a)* Prefabricated or preformed pressure parts for pressure vessels that are subject to stresses due to pressure and that are furnished by others or by the Manufacturer of the completed vessel shall conform to all applicable requirements of this Division except as permitted in 3.2.8.2, 3.2.8.3, 3.2.8.4, and 3.2.8.5. 3.2.8.2 Cast, Forged, Rolled, or Die-Formed Nonstandard Pressure Parts. 3.2.8.3 Cast, Forged, Rolled, or Die-Formed Standard Pressure Parts, Either Welded or Nonwelded, That Comply with an ASME Product Standard. 3.2.8.4 Cast, Forged, Rolled, or Die-Formed Standard Pressure Parts, Either Welded or Nonwelded, That Comply with a Standard Other Than an ASME Product Standard. 3.2.8.5 The Code recognizes that a Certificate of Authorization Holder may fabricate parts in accordance with 3.2.8.4, and that are marked in accordance with 3.2.8.4*(h)*.	This rule revises and adds requirements for prefabricated or preformed pressure parts furnished without a Code Stamp. Revisions and additions of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
3.3.7 Clad Tubesheets	3.3.7 was added to state: 3.3.7.1 states: Tube-to-tubesheet welds in the cladding of either integral or weld metal overlay clad tubesheets may be	This rule adds requirements for clad tubesheets. Additions of this rule does not violate the fundamental safety assumptions

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Evaluation
	considered strength welds (full or partial), provided the welds meet the design requirements of 4.18.10. In addition, when the strength welds are to be made in the clad material of integral clad tubesheets, the integral clad material to be used for tubesheets shall meet the requirements in (a) and (b) for any combination of clad and base materials. The shear strength test and ultrasonic examination specified in (a) and (b) are not required for weld metal overlay clad tubesheets.	stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
3.11.2 Carbon and Low Alloy Steels Except Bolting	3.11.2.1*(b)(2)* in the 2007 and 2021 editions states: If the specified minimum tensile strength is greater than or equal to 655 MPa (95 ksi), then the minimum lateral expansion (see Figure 3.5) opposite the notch for all specimen sizes shall not be less than the values shown in Figure 3.6. The lateral expansion limits for broken Charpy V-Notch specimens shown in Figure 3.6 in the 2007 edition range from 15 to 25 mils. Whereas the lateral expansion limits for broken Charpy V-Notch specimens shown in Figure 3.6 in the 2007 edition range from 20 to 32 mils.	This rule in the 2021 edition revises the lateral expansion limits in Figure 3.6 for broken Charpy V-Notch specimens. This revision resulted from analytical work was performed to assess the toughness requirements of these materials. As a result of this work, the lateral expansion requirements shown in Figures 3.6 were increased, resulting in an average increase of approximately 30% in the lateral expansion limits (See Sect. 4.1.3.3 of this report). Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent or greater safety.
3.11.2 Carbon and Low Alloy Steels Except Bolting	3.11.2.2 – Required Impact Testing Based on the MDMT, Thickness, and Yield Strength was revised to state: (a) If the governing thickness (see 3.11.2.3(b) at any welded joint or of any nonwelded part exceeds 100 mm (4 in.) and the MDMT is colder than 43°C (110°F), then impact testing is required. (b) Materials having a specified minimum yield strength greater than 450 MPa (65 ksi) shall be impact tested.	This rule revises requirements for minimum design metal temperature (MDMT) for carbon and low alloy steels except bolting materials below which impact testing is mandatory for governing thickness greater than 100 mm (4 in.) was changed from 32°C (90°F) to 43°C (110°F). This change was necessary to obtain agreement between the observed behavior of the materials and the asymptotic limit of Curve A (see Figures 3.7, 3.7M, 3.8, and 3.8M.). Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
3.11.8.2 Location, Orientation, Temperature, and Values of Weld Impact Tests	3.11.8.2*(g)* was added to state: When qualifying a WPS for welding base metals having different impact testing requirements and acceptance criteria, the following shall apply: *(1)* The weld metal impact test specimens shall meet the acceptance criteria for either base metal.	This rule addition specifies acceptance criteria for qualifying a WPS for welding base metals having different impact testing requirements. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007

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	(2) When HAZ tests are required, separate test specimens shall be removed from the HAZ of each base metal that requires impact testing, and those specimens shall meet the acceptance criteria for the base metal from which they were removed.	edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
Annex 3-D Strength Parameters (Normative)	3-D.1 – Yield Strength Values for the yield strength as a function of temperature are provided in Section II, Part D, Subpart 1, Table Y-1. If the material being used is not listed in Table Y-1, while being listed in other tables of Section II, Part D. Subpart 1, or the specified temperature exceeds the highest temperature for which a value is provided, the yield strength may be determined as in *(a)* and *(b)* for use in the design equations in Part 4. S is the maximum allowable stress of the material at the temperature specified [see Annex 3-A] and f is the factor (e.g., weld factor) used to determine the allowable stress as indicated in the notes for the stress line. If the value of f is not provided, set f equal to 1. *(a)* If the allowable design stress is established based on the 66 2/3% yield criterion, then the yield strength, S_y, shall be taken as $1.5S/f$. *(b)* If the allowable design stress is established based on yield criterion between 662/3% and 90%, then the yield strength, S_y shall be taken as $1.1S/f$.	This Annex adds rules for establishing allowable design stresses for materials not listed in Section II, Part D, Subpart 1, Table Y-1 in the ASME BPVC. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
Annex 3-F Design Fatigue Curves (Normative)	3-F in the 2021 edition includes additional design fatigue curves in the following paragraphs. 3-F.1 Smooth Bar Design Fatigue Curves 3-F.2 Welded Joint Design Fatigue Curves	This rule adds design fatigue curves for smooth bars and welded joints. Addition of design fatigue curves for smooth bars and welded joints does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
Part 4 – Design by Rule Requirements		
4.1.1 Scope	4.1 – General Requirements, Paragraph 4.1.1.2 was revised to state: Part 4 does not provide rules to cover all loadings, geometries, and details. See Part 2 for User Responsibilities and User's Design Specification.	This rule adds general requirements for Class 1 and Class 2 construction. Addition of general requirements for Class 1 and Class 2 construction does not violate the fundamental safety assumptions stated or implied in the 2007 edition of

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	General requirements were added to: 4.1.1.2.1 – Class 1 4.1.1.2.2 – Class 2	Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
4.1.1 Scope	4.1.1.3 was revised to state: The design procedures in Part 4 may be used if the allowable stress at the design temperature is governed by time-independent or time-dependent properties unless otherwise noted in a specific design procedure. When the vessel is operating at a temperature where the allowable stress is governed by time dependent properties, the effects of joint alignment (see 6.1.6.1) and weld peaking (see 6.1.6.3) in shells and heads shall be considered.	This rule adds requirements for consideration of weld seam peaking for vessels that operate in the creep regime. Current rules establish limits on weld peaking for vessels in fatigue service. This revision will now require similar limits when the vessel operates in the creep regime. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
4.1.1 Scope	4.1.1.5 was revised to state: See 4.1.1.5.1 and 4.1.1.5.2. 4.1.1.5.1 – Class 1. Rules in Part 5 shall not be used in lieu of rules in Part 4. 4.1.1.5.2 – Class 2. A design-by-analysis in accordance with Part 5 may be used to establish the design thickness and/or configuration (i.e., nozzle reinforcement configuration) in lieu of the design-by-rules in Part 4 for any geometry or loading conditions (see 4.1.5.1). Components of the same pressure vessel may be designed (thickness and configuration) using a combination of Part 4 design-by-rules or any of the three methods of Part 5 design-by-analysis in 5.2.1.1. Each component shall be evaluated for all of the applicable failure modes in 5.1.1.2 using the methodology of Part 4 or Part 5. If the failure mode is not addressed in Part 4 (e.g., ratcheting), then the analysis shall be in accordance with Part 5. Structural interactions between components shall be considered.	These rules revise general requirements for Class 1 and Class 2 construction. Revision of these rules does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
4.1.2 Minimum Thickness Requirements	4.1.2*(d)* states: This minimum thickness does not apply to the tubes in air cooled and cooling tower heat exchangers if all of the following provisions are met: 4.1.2*(d)(3)* was revised to state: The minimum thickness used shall not be less than that calculated by the equations given in 4.3 and in no case less than 0.5 mm (0.022 in.).	This rule revises minimum thickness requirements for tubes in air cooled and cooling tower heat exchangers. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent or greater safety.

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4.1.5 Design Basis	4.1.5.1 – Design Thickness was revised to state: The design thickness of the vessel part shall be determined using the rules specified in 4.1.5.1.1 or 4.1.5.1.2 and shall not be less than the minimum thickness specified in 4.1.2 plus any corrosion allowance required by 4.1.4. 4.1.5.1.1 – Class 1 design thickness requirements are added. 4.1.5.1.2 – Class 2 design thickness requirements are added.	This rule adds design thickness requirements for Class 1 and Class 2 construction. Addition of these rules does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
4.1.5.3 Design Loads and Load Case Combinations	4.1.5.3 states: All applicable loads and load case combinations shall be considered in the design to determine the minimum required wall thickness for a vessel part. 4.1.5.3*(b)* was revised to state: The load combinations that shall be considered shall include, but not be limited to, those shown in Table 4.1.2 – Design Load Combinations, except when a different recognized standard for wind loading is used. In that case, the User's Design Specification shall cite the Standard to be applied and provide suitable load factors if different from ASCE/SEI 7 [10]. The factors for wind loading, W, in Table 4.1.2, are based on ASCE/SEI 7 wind maps and probability of occurrence. If a different recognized standard for earthquake loading is used, the User's Design Specification shall cite the Standard to be applied and provide suitable load factors if different from ASCE/SEI 7.	This rule revises requirements for loads and load combinations for use in determining the minimum required wall thickness for a pressure vessel part (See Sect. 4.2.3 of this report). Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent or greater safety.
4.1.6 Design Allowable Stress	4.1.6.2 – Test Condition was revised in its entirety and provides equations for establishing the maximum hydrostatic and pneumatic test pressure. Variables used in the equations are given in Table 4.1.3 – Load Factor, β, and Pressure Test Factors, β_T, γ_{min}, and $\frac{\gamma_{St}}{S}$ for Class 1 and Class 2 Construction and Hydrostatic or Pneumatic Testing.	This rule revises requirements for establishing the maximum hydrostatic and pneumatic test pressure (See Sect. 7.1.3 of this report). Corresponding maximum allowable primary membrane stress values permitted in the 2007 edition and the 2021edition for hydrostatic and pneumatic are the same. Maximum allowable primary membrane stress values for Class 1 and Class 2 Construction also the same. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2

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		of the ASME BPVC and therefore provide equivalent or greater safety.
4.1.6 Design Allowable Stress	4.1.6.3 – Primary Plus Secondary Stress states: The allowable primary plus secondary stress at the design temperature shall be computed as follows: $$S_{PS} = \max[3S, 2S_y]$$ However, S_{PS} shall be limited to $3S$ if either *(a)* the room temperature ratio of the minimum specified yield strength from Annex 3-D to the ultimate tensile strength from Annex 3-D exceeds 0.70; or, *(b)* the allowable stress from Annex 3-A is governed by time-dependent properties.	This rule for allowable primary plus secondary stress in the 2021 edition is the same as the rule in the 2007 edition. Annex 3-D – Strength Parameters (Normative) on the 2007 and 2021 editions defines models for the stress–strain curve to be used in design calculations where required by this Division when the strain hardening characteristics of the stress–strain curve are to be considered (See Sect. 4.7 of the report). This rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent or greater safety.
4.1.6 Design Allowable Stress	4.1.6.4 – Shear Stress states: The maximum shear stress in restricted shear, such as dowel bolts or similar construction in which the shearing member is so restricted that the section under consideration would fail without a reduction of area, shall be limited to 0.80 times the values in Section II, Part D, Subpart 1, Table 3.	This rule for allowable shear stress was added to limit shear stress to 0.80 times the values in Section II, Part D, Subpart 1, Table 3. Shear stress is a component of stress tangent to the plane of reference, Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent or greater safety.
4.1.6 Design Allowable Stress	4.1.6.5 – Bearing Stress states: Maximum bearing stress shall be limited to 1.60 times the values in Section II, Part D, Subpart 1, Table 3.	This rule for allowable bearing stress was added to limit bearing stress to 1.60 times the values in Section II, Part D, Subpart 1, Table 3. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent or greater safety.
4.2.5.1 Definitions	*(d)* Spiral Weld was added to state: a weld joint having a helical seam.	This rule adds a definition for spiral weld. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
4.3.11 Cylindrical-to-Conical Shell	4.3.11.4 *Step 6* was revised by changing the way F_{ha} is evaluated. (See Code Case 2286.)	This rule revises requirements for determining if local buckling is not a concern for design of the large end of a

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Transition Junctions without a Knuckle		cylinder-to-cone junction without a knuckle. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
4.3.11 Cylindrical-to-Conical Shell Transition Junctions without a Knuckle	4.3.11.5 *Step 6* was revised to state: Local buckling is not of concern if the limits given in eqs. (4.3.54) and (4.3.55) are satisfied, using the procedure provided in 4.3.11.4, Step 6. (See Code Case 2286.)	This rule revises requirements for determining if local buckling is not a concern for design of the small end of a cylinder-to-cone junction without a flare. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
4.3.12 Cylindrical-to-Conical Shell Transition Junctions with a Knuckle	4.3.12.2 *Step 5* was revised by changing the way F_{ha} is evaluated. (See Code Case 2286.)	This rule revises requirements for computing the stresses in the cylinder, knuckle, and cone at the junction using the equations in Table 4.3.7. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
4.3.12 Cylindrical-to-Conical Shell Transition Junctions with a Knuckle	4.3.12.2 *Step 5* was revised to state: Local buckling is not of concern if the limits given in eqs. (4.3.67) and (4.3.68) are satisfied, using the procedure provided in 4.3.12.2, Step 5. (See Code Case 2286.)	This rule revises requirements for determining if local buckling is not a concern for design of the small end of a cylinder-to-cone junction with a flare. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
4.4.3 Material Properties	4.4.3.2 was revised to state: An example of an iterative solution to determine F_{ic} is shown in Table 4.4.2 – Algorithm for Computation of Predicted Inelastic Buckling Stress, F_{ic}.	This rule revises the provisions for an example of an iterative solution to determine F_{ic}. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
4.5.13 Spacing Requirements for Nozzles	4.5.13.1 was added to state: The limit of reinforcement, L_R (see Figures 4.5.1 and 4.5.2), for a nozzle shall not overlap with a gross structural discontinuity (see 4.2.5.1). The limit of reinforcement, L_S (see Figure 4.5.11), may be reduced from the maximum permitted by other rules to allow closer placement of nozzles so long as all opening reinforcement requirements are satisfied.	This rule adds requirements for the limit of reinforcement for a nozzle. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.

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	Paragraph 4.5.13.1 in the 2007 edition was redesignated to 4.5.13.2 in the 2021 edition.	
4.5.18 Nomenclature	4.5.18 revised to state: A_2 = area contributed by the nozzle outside the vessel wall. A_{2a}= portion of area *A*2 for variable nozzle wall thickness, contributed by the nozzle wall within L_{pr3} (see Figures 4.5.13 and 4.5.14). L_{pr3} A_{2b} =portion of area A_2 for variable nozzle wall thickness, contributed by the nozzle wall outside of L_{pr3} when $L_H \leq L_{x4}$ (see Figures 4.5.13 and 4.5.14). A_{2c}= portion of area A_2 for variable nozzle wall thickness, contributed by the nozzle wall outside of L_{pr3} when $L_H \leq L_{x4}$ (see Figures 4.5.13 and 4.5.14).	This rule revises and clarifies requirements for set-in versus set-on nozzles, calculation of the area "A_2" for variable thickness nozzles, consistency in the determination of the pressure area for all nozzle geometries, correction of the pressure area calculation for radial nozzles in conical shells, modifications to the limits of reinforcement for radial nozzles in spheres/formed heads, consolidation of design rules for hillside and perpendicular nozzles in formed heads, and the addition of a pressure thrust load check on weld strength. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
4.7.2 Type A Head Thickness Requirements	4.7.2.2 was revised to state: The flange thickness of the head for a Type A Head Configuration shall be determined in accordance with the rules of 4.16. When a slip-on flange conforming to the standards listed in Table 1.1 is used, design calculations per 4.16 need not be done, provided the design pressure–temperature is within the pressure–temperature rating permitted in the flange standard.	This rule revises and clarifies Type A head thickness requirements. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
4.16.7 Flange Design Procedure	4.16.7.2 *w*as revised to state: *Step 6.* Determine the flange moment for the operating condition using Equation (4.16.14) or Equation (4.16.15), as applicable. When specified by the user or his designated agent, the maximum bolt spacing (B_{smax}) and the bolt spacing correction factor (B_{SC}) shall be applied in calculating the flange moment for internal pressure using the equations in Table 4.16.11. The flange moment M_o for the operating condition and flange moment M_g for the gasket seating condition without correction for bolt spacing $B_{SC} = 1$ is used for the calculation of the rigidity index in Step 10. In these equations, h_D, h_T, and h_G are determined from Table 4.16.6. For integral and loose type flanges, the moment M_{oe} is calculated using Equation (4.16.16) where I and I_p in this equation are determined from Table 4.16.7. For reverse type	This rule revises requirements for a bolt spacing correction factor to the flange design procedure. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.

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	flanges, the procedure to determine M_{oe} shall be agreed upon between the Designer and the Owner.	
4.17.4 Design Bolt Loads	4.17.4.2 The procedure to determine the bolt loads for the operating, and gasket seating and assembly conditions are shown below. The following note was added to Step 7. NOTE: In addition, the Manufacturer shall provide to the User a copy of the bolting instructions that were used. It is recommended that the Manufacturer refer to ASME PCC-1, *Guidelines for Pressure Boundary Bolted Flange Joint Assembly*. It is cautioned that bolt loads in excess of those calculated using eq. (4.17.10) can overstress the clamp.	This rule revises requirements for clamp connection rules with an updated warning note. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
4.18.3 General Design Considerations	4.18.3*(a)* was revised to state: The design of all components shall be in accordance with the applicable rules of all Parts of this Division. The remainder of paragraph 4.18.3 was revised and includes Figure 4.18.19 Nozzles Adjacent to Tubesheets.	This rule revises requirements to 4.18 – Design Rules for Shell-and-Tube Heat Exchangers by revising 4.18.3 and adding Figure 4.18.19. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
4.18.4 General Considerations of Applicability for Tubesheets	4.18.4*(a)* states: The tubesheet shall be flat and circular. The remainder of Paragraph 4.18.4 was revised to include Paragraph 4.18.4*(b)* through *(g)*.	This rule revises and adds requirements to 4.18.4 – General Considerations of Applicability for Tubesheets. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
4.18.8.4 Calculation Procedure	4.18.8.4 *Step 9(c)(1)* was revised to state: Calculate the largest tube-to-tubesheet joint load, W_t.	This rule revises requirements for calculating the largest tube-to-tubesheet joint load for use in checking the tube-to-tubesheet joint design. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
4.18.15*(d)* Nomenclature for the design of fixed or floating tubesheets	4.18.15*(d)* Nomenclature for the design of fixed or floating tubesheets was revised to state: T' = tubesheet metal temperature at the rim (see Figure 4.18.18).	This rule adds Figure 4.18.18 to show the location of tubesheet metal temperature at the rim. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.

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4.20 Design Rules for Flexible Shell Element Expansion Joints	4.20 – Design Rules for Flexible Shell Element Expansion Joints was added. 4.20.1 – Scope *(a)* states: The rules in 4.20 cover the minimum requirements for the design of flexible shell element expansion joints used as an integral part of heat exchangers or other pressure vessels. These rules apply to single-layer flexible shell element expansion joints shown in Figure 4.20.1 and are limited to applications involving axial displacement only. The suitability of an expansion joint for the specified design pressure, temperature, and axial displacement shall be determined by the methods described herein.	This rule replaces the rules in the 2007 edition from 4.18.12.1 that required flanged and flued expansion joints to be designed per Part 5 of Division 2. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
4.21 Tube-to-Tubesheet Joint Strength	4.21 Tube-to-Tubesheet Joint Strength was added. 4.21.1 Scope 4.21.1.1 General *(a)* Tubes used in the construction of heat exchangers or similar apparatus may be considered to act as stays that support or contribute to the strength of tubesheets in which they are engaged. Tube-to-tubesheet joints shall be capable of transferring the applied tube loads. The design of tube-to tubesheet joints depends on the type of joint, degree of examination, and shear load tests, if performed.	This rule adds requirements for determining the strength of Tube-to-tubesheet joint. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent or greater safety.
Annex 1.A Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committee (Normative)	Annex 1.A was deleted in the 2021 edition.	The 2021 edition includes Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees as part of the front matter in Section VIII, Division 2.
Annex 4-C Basis for Establishing Allowable Loads for Tube-to-Tubesheet Joints	Annex 4-C is not included in the 2021 edition.	An equivalent safety evaluation of Annex 4-C is not possible.
Annex 4-D Guidance to Accommodate Loadings Produced by	Annex 4-D – Guidance to Accommodate Loadings Produced by Deflagration was added. 4-D.1 – Scope states: When an internal vapor-air or dust-air deflagration is defined by the user or his designated agent as a	This rule adds guidance to accommodate loadings produced by deflagration. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007

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Deflagration (Normative)	load condition to be considered in the design, this Annex provides guidance for the designer to enhance the ability of a pressure vessel to withstand the forces produced by such conditions.	edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent or greater safety.
Annex 4-E Tube Expanding Procedures and Qualification (Informative)	Annex 4-E Tube Expanding Procedures and Qualification was added. 4-E.2 – Scope states: The rules in this Annex apply to preparation and qualification of tube expanding procedures for the types of expanding processes permitted in this Annex.	This rule adds requirements for tube expanding procedures and qualification. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
Part 5 – Design by Analysis Requirements		
5.1.1.2	*(b)* Protection Against Local Failure was revised to state: These requirements apply to all components where the thickness and configuration of the component is established using design-by-analysis rules. It is not necessary to evaluate the protection against local failure, 5.3, if the component design is in accordance with Part 4 (e.g., component wall thickness and weld detail per 4.2).	This rule revision requires a local failure check when the design is not based on Part 4 rules. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
5.1.1.3.1 Class 1	5.1.1.3.1 was added to states: The design-by-analysis procedures in Part 5 shall not be used unless allowed by 4.1.1.2.1.	This rule adds requirements for Class 1 construction. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
Part 6 – Fabrication Requirements		
6.1.2 Forming	6.1.2 provides revised rule for forming carbon and low alloy material, high alloy material, and nonferrous material parts. Requirements are tabulated in: Table 6.1 Equations for Calculating Forming Strains Tables 6.2.A Post-Cold-Forming Strain Limits and Heat-Treatment Requirements for P-No. 15E Materials Tables 6.2.B Post-Fabrication Strain Limits and Required Heat Treatment for High Alloy Materials Table 6.3 Post-Fabrication Strain Limits and Required Heat Treatment for Nonferrous Materials	This rule revises requirements for forming carbon and low alloy material, high alloy material, and nonferrous material parts. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.

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6.1.6.3 Peaking of Welds in Shells and Heads for Internal Pressure	6.1.6.3*(a)* was revised to state: If the vessel is operating at a temperature where the allowable stress is governed by time dependent properties, see 4.1.1.3, or if a fatigue analysis is required, see 4.1.1.4, then the peaking height, p_d at Category A weld joints shall be measured by either an inside or outside template, as appropriate (see Figure 6.1). As an alternative, the peaking angle may be determined using the procedure described in Part 8 of API 579-1/ASME FFS-1.	This rule revises the requirements for peaking of welds in shells and heads for internal pressure. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
Annex 6-A Positive Material Identification Practice (Informative)	Annex 6-A – Positive Material Identification Practice was added. 6-A.1.1 states: When required by the User's Design Specification (UDS), a Manufacturer may be required to perform positive material identification (PMI) of a specific material, component, or weld. This may include components used by the Manufacturer for the fabrication of pressure-retaining parts and supports, raw material covered by ASME material specifications, overlay deposits, or components of fabricated vessels. This Annex is provided as a guide for use by the Manufacturer in developing a PMI procedure that may be used to test the raw material, component, vessel, or other item, and to evaluate the results.	This rule adds guidance for use by the Manufacturer in developing a positive material identification (PMI) procedure that may be used to test the raw material, component, vessel, or other item, and to evaluate the results. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
Part 7 – Responsibilities and Duties for Inspection and Examination Activities		
7.3 Qualification of Nondestructive Examination Personnel	7.3 was retitled and revised in its entirety to state: Personnel performing nondestructive examinations in accordance with 7.5.3, 7.5.4, 7.5.5, 7.5.6, 7.5.7, or 7.5.8 shall be qualified and certified in accordance with the requirements of Section V, Article 1, T-120*(e)*, T-120*(f)*, T-120*(g)*, T-120*(i)*, T-120*(j)*, or T-120*(k)*, as applicable.	This rule revises requirements for qualification of nondestructive examination personnel. Revision of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.
7.4.3.6 Thickness.	7.4.3.6 was added to state: When cited in the acceptance criteria of the various examination methods in 7.5 and Table 7.2, the thickness t is defined as the thickness of the weld, excluding any allowable reinforcement [see 6.2.4.1*(d)*]. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld	This rule adds requirements for determining the thickness of welds for examination of welded joints. Addition of this rule does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Evaluation
	includes a fillet weld, the thickness of the throat of the fillet shall be included in t.	
	Part 8 – Pressure Testing Requirements	
8.1.5 Test Gaskets and Fasteners	Custom-designed flange assemblies, including modified standard flange assemblies where additional calculations are required, within the geometric scope of this Division (see 1.2.3 and 4.16.7) shall be tested with gaskets and bolting that meet the following requirements:	This rule adds pressure test requirements for custom-designed flange assemblies.
8.2 Testing	8.2 – Testing was revised in its entirety to be consistent with 4.1.6.2 – Test Condition. 8.2.1 – Test Pressure states: *(a)* states*:* Except as noted for vessels of specific construction identified in 8.1.3, or enameled vessels whose test pressure shall be at least the MAWP to be marked on the vessel, the minimum test pressure shall be computed from eq. 8.1 where $\gamma_{St/S}$ shall be obtained from Table 4.1.3 for the applicable test medium and class. $$P_t = \gamma_{St/S}\ \text{MAWP}\left(\frac{S_t}{S}\right) \quad (8.1)$$ *(b)* The ratio S_t/S in eq. (8.1) shall be the lowest ratio for the pressure-boundary materials, excluding bolting materials, of which the vessel is constructed. *(c)* The requirement of (a) represents the minimum required test pressure. The upper limits of the test pressure shall be determined using the method in 4.1.6.2, 5.2.2.5, 5.2.3.6, or 5.2.4.5. Any intermediate value of pressure may be used. *(d)* The test pressure is the pressure to be applied at the top of the vessel during the test. This pressure plus hydrostatic head, if applicable, is used in the applicable design equations to check the vessel under test conditions, 4.1.6.2. *(e)* A pressure test based on a calculated pressure may be used by agreement between the user and the Manufacturer. The test pressure at the top of the vessel shall be the minimum of	This rule in 8.2.1 establishes the minimum test pressure for Class 1 and Class 2 construction to: $$P_t = 1.25\ \text{MAWP}\left(\frac{S_t}{S}\right)$$ for hydrostatic testing, or $$P_t = 1.15\ \text{MAWP}\left(\frac{S_t}{S}\right)$$ for pneumatic testing (See Sect. 7.1.3 of this report). 8.3 – Pneumatic Testing in the 2007 edition was deleted and 8.4 through 8.6 in the 2007 edition were redesignated to 8.3 through 8.5 in the 2021 edition.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Evaluation
	the test pressures calculated by multiplying the basis for the calculated test pressure for each pressure element as shown in eq. (8.1) and reducing this value by the hydrostatic head on that element. The basis for this calculated test pressure is the highest permissible internal pressure, as determined by the design equations, for each element of the vessel using the nominal thicknesses, including corrosion allowance, and the allowable stress values given in Annex 3-A for the temperature of the test. When this pressure is used, it shall be as set forth in the Manufacturer's Design Report.	
Part 9 – Pressure Vessel Overpressure Protection		
Part 9 Pressure Vessel Overpressure Protection	All Division 2 pressure relief device requirements have been transferred from Part 9 to Section XIII – Rules for Overpressure Protection, and the remaining Division 2 overpressure protection requirements have been restructured within Part 9.	Annex 9-B – Guide to the Relocation of Overpressure Protection Requirements provides a complete cross-reference list in Table 9-B.1-1 – Cross-Reference List. This cross-reference lists the new locations for all the affected requirements in the 2021 edition of Section VIII, Division 2 of the ASME BPVC. Part 9 has been revised to reference this Annex 9-B. The reference and this Annex will be deleted from the next edition of this Division.
9.1 General Requirements	*(a)* states: This Part provides the acceptable methods and requirements for overpressure protection for pressure vessels constructed to the requirements of this Division. Acceptable methods include pressure relief devices, open flow paths, and overpressure protection by system design. It establishes the type, quantity and settings of acceptable pressure relief devices, and relieving capacity requirements including maximum allowed relieving pressures. Unless otherwise specified, the required pressure relief devices shall be constructed, capacity certified, and bear the ASME Certification Mark in accordance with Section XIII. In addition, this Part	Section XIII – Rules for Overpressure Protection provides rules for the overpressure protection of pressurized equipment such as boilers, pressure vessels, and piping systems. This standard provides requirements for topics such as design, material, inspection, assembly, testing, and marking for pressure relief valves, rupture disk devices, pin devices, spring-actuated non-reclosing devices, and temperature and pressure relief valves. This standard also covers devices in combination, capacity and flow resistance certification, authorization to use the ASME Certification Mark, installation, and overpressure protection by system design.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section VIII, Division 2 of the ASME BPVC	Equivalent Safety Evaluation
	provides requirements for installation of pressure relief devices.	

Table 9.9 Evaluation of equivalent safety for rules and requirements revised or added to the 2021 edition of Section IX of the ASME BPVC

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section IX of the ASME BPVC	Equivalent Safety Evaluation
Part QG General Requirements	Part QG – General Requirements was added to Section IX – Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators. Part QG was not included in the 2007 edition of Section IX of the ASME BPVC. Part QG contains Paragraphs QG-100 through QG-109.	Addition of general requirements in Part QG to Section IX does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section IX of the ASME BPVC and therefore provide equivalent safety.
Paragraph QG-100	QG-100 – Scope states: *(a)* This Section contains requirements for the qualification of welders, welding operators, brazers, brazing operators, plastic fusing operators, and the material joining processes they use during welding, brazing, and fusing operations for the construction of components under the rules of the ASME Boiler and Pressure Vessel Code, the ASME B31 Codes for Pressure Piping, and other Codes, standards, and specifications that reference this Section. Section IX is divided into four parts. (1) Part QG contains general requirements for all material-joining processes. (2) Part QW contains requirements for welding. (3) Part QB contains requirements for brazing. (4) Part QF contains requirements for plastic fusing.	The 2021 edition does not include Part QG – General Requirements so an equivalent safety evaluation is not possible.
Paragraph QG-101 (See Sect. 5.3.3 of this report.)	QG-101 – Procedure Specification states: A procedure specification is a written document providing direction to the person applying the material joining process. Details for the preparation and qualifications of procedure specifications for welding (WPS), brazing (BPS), and fusing (FPS) are given in the respective Parts addressing those processes. Part QW contains requirements for welding. Part QB contains requirements for brazing. Part QF contains requirements for plastic fusing.	The 2021 edition does not include Part QG – General Requirements so an equivalent safety evaluation is not possible.
Paragraph QG-102 (See Sect. 5.3.4 of this report.)	QG-102 – Procedure Qualification Record states: The purpose of qualifying the procedure specification is to demonstrate that the joining process proposed for construction is capable of producing joints having the required mechanical properties for the intended application.	The 2021 edition does not include Part QG – General Requirements so an equivalent safety evaluation is not possible.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section IX of the ASME BPVC	Equivalent Safety Evaluation
	The procedure qualification record (PQR) documents what occurred during the production of a procedure qualification test coupon and the results of testing that coupon. As a minimum, the PQR must document the essential procedure qualification test variables applied during production of the test joint, and the results of the required tests. Rules for procedure qualification for the following joining processes are specified in: Article II – Welding Article XII – Brazing Article XXII – Plastic Fusing	
Paragraph QG-103 (See Sect. 5.3.5 of this report.)	QG-103 – Performance Qualification states: The purpose of qualifying the person who will use a joining process is to demonstrate that person's ability to produce a sound joint when using a procedure specification. Rules for performance qualification for the following joining processes are specified in: Article III – Welding Article XIII – Brazing Article XXIII – Plastic Fusing	The 2021 edition does not include Part QG – General Requirements so an equivalent safety evaluation is not possible.
Paragraph QG-104 (See Sect. 5.3.6 of this report.)	QG-104 – Performance Qualification Record states: The performance qualification record documents what occurred during the production of a test coupon by a person using one or more joining processes following an organization's procedure specification. Rules for performance qualification record data for the following joining processes are specified in: Article IV – Welding Article XIV – Brazing Article XXIV – Plastic Fusing As a minimum, the record must document: (a) the essential variables for each process used to produce the test coupon (b) the ranges of variables qualified as required by the applicable part (see QW-301.4, QB-301.4, and QF-301.4) (c) the results of the required testing and nondestructive examinations	The 2021 edition does not include Part QG – General Requirements so an equivalent safety evaluation is not possible.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section IX of the ASME BPVC	Equivalent Safety Evaluation
	(d) the identification of the procedure specification(s) followed during the test	
Paragraph QG-105	QG-105 – Variables includes rules for: QG-105.1 – Essential Variables (Procedure). QG-105.2– Essential Variables (Performance). QG-105.3 – Supplementary Essential Variables. QG-105.4 – Nonessential Variables. QG-105.5 – Special Process Variables. QG-105.6 – Applicability. Rules for variables for the following joining processes are specified in: Article IV – Welding Article XIV – Brazing Article XXIV – Plastic Fusing	The 2021 edition does not include Part QG – General Requirements so an equivalent safety evaluation is not possible.
Paragraph QG-106	QG-106 – Organizational Responsibility states: Personnel performing supervisory activities specified in this Section shall: (a) be designated by the organization with responsibility for certifying qualification documents. (b) have a satisfactory level of competence in accordance with the organization's quality program. As a minimum, they shall be qualified by education, experience, or training in the following areas: (1) knowledge of the requirements of this Section for the qualification of procedures and/or joining personnel (2) knowledge of the organization's quality program (3) the scope, complexity, or special nature of the activities to which oversight is to be provided (c) have a record, maintained by the organization, containing objective evidence of the qualifications, training, or experience. QG-106.1 – Procedure Qualifications. QG-106.2 – Performance Qualifications. QG-106.3 – Simultaneous Performance Qualifications.	The 2021 edition does not include Part QG – General Requirements so an equivalent safety evaluation is not possible.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section IX of the ASME BPVC	Equivalent Safety Evaluation
Paragraph QG-107	QG-107 – Ownership Transfers states: Organizations may maintain effective operational control of PQRs, procedure specifications, and performance qualification records under different ownership than existed during the original procedure qualification. Multiple organizations under a common ownership may use PQRs, procedure specifications, and performance qualification records under that owner's name. The Quality Control System or Quality Assurance Program of each organization shall describe the effective operational control and authority for technical direction of welding.	The 2021 edition does not include Part QG – General Requirements so an equivalent safety evaluation is not possible.
Paragraph QG-108	QG-108 – Qualifications Made to Previous Editions states: Joining procedures, procedure qualifications, and performance qualifications that were made in accordance with Editions and Addenda of this Section as far back as the 1962 Edition may be used in any construction for which the current Edition has been specified.	The 2021 edition does not include Part QG – General Requirements so an equivalent safety evaluation is not possible.
Paragraph QG-109	QG-109 – Definitions includes: Paragraph QG-109.1 – General that states: Definitions of the more common terms relating to material-joining processes are defined in QG-109.2. There are terms listed that are specific to ASME Section IX and are not presently defined in AWS A3.0. Several definitions have been modified slightly from AWS A3.0 so as to better define the context or intent as used in ASME Section IX. Paragraph QG-109.2 – Definitions	The 2021 edition does not include Part QG – General Requirements so an equivalent safety evaluation is not possible.
QW-191.4 Personnel Qualifications and Certifications (See Sect. 6.3.1 of this report.)	QW-191.4 was added to state: (a) All personnel performing volumetric examinations for welder and welding operator qualifications shall be qualified and certified in accordance with their employer's written practice. (b) The employer's written practice for qualification and certification of examination personnel shall meet all applicable requirements of Section V, Article 1.	This rule adds qualification requirements for personnel performing volumetric examinations for welder and welding operator that meet all applicable requirements of Section V, Article 1. Addition of general requirements in Part QG to Section IX does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section IX of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section IX of the ASME BPVC	Equivalent Safety Evaluation
	(c) If the weld being examined is a production weld, the examiner may be qualified and certified in accordance with the requirements of the referencing code as an alternative to the requirements of this paragraph.	
QW-202.2 Groove and Fillet Welds	QW-202.2*(a)* – Qualification for Groove Full Penetration Welds was revised to add the following sentences that states: When dissimilar thickness test coupons are welded, the "Range of Thickness *T* of Base Metal, Qualified" in QW-451 shall be determined individually for each base metal in the test coupon. When the thicker test coupon is tapered to provide a thickness transition at the weld, the qualified range shall be based on the base metal thickness adjacent to the toe of the weld at the thinnest end of the transition. The test specimens for tensile and bend tests may be machined to the thickness required for the thinner base metal prior to testing.	This rule adds requirements for dissimilar thickness test coupons. Addition of this requirements to Paragraph QW-202.2*(a)* does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section IX of the ASME BPVC and therefore provide equivalent safety.
QW-220 Hybrid Welding Procedure Variables	QW-220 was added to state: Requirements of QW-221 through QW-223 shall be observed for all hybrid welding procedure qualifications.	This rule adds requirements for all hybrid welding procedure qualifications. Addition of this requirements to Paragraph QW-220 does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section IX of the ASME BPVC and therefore provide equivalent safety.
QW-221 Essential Variables for Hybrid Welding	QW-221 was added to state: The following essential variables are in addition to the welding variables for each welding process used during hybrid welding provided in QW-250: *(a)* an addition or deletion of welding processes used in a hybrid welding process from those used during qualification. *(b)* a change in the process sequence used in a hybrid welding process from that used during qualification. *(c)* a change in the process separation used in a hybrid welding process greater than 10% from that used during qualification (e.g., measured at the weld surface, measured between the welding torch and laser, etc.) *(d)* a change in any angle, between each individual welding process used in a hybrid welding process or a change in any angle between the hybrid welding process and the	This rule adds requirements for addition essential variables for hybrid welding. Addition of this requirements to Paragraph QW-221 does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section IX of the ASME BPVC and therefore provide equivalent safety.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section IX of the ASME BPVC	Equivalent Safety Evaluation
	material to be welded, of greater than 10 deg from that used during qualification. *(e)* a change in the height between the individual welding processes used in a hybrid welding process and the material surface or a change in the height between the hybrid welding process and the material surface greater than 10% from that used during qualification.	
QW-222 Welding Process Restrictions	QW-222 was added to state: The hybrid welding process shall be limited to machine or automatic welding.	This rule adds requirements for hybrid welding processes. Addition of this requirements to Paragraph QW-222 does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section IX of the ASME BPVC and therefore provide equivalent safety.
QW-223 Test Coupon Preparation and Testing	QW-223 was added to state: The hybrid welding procedure qualification test coupon shall be prepared in accordance with the rules in QW-210 and tested in accordance with the rules in QW-202.	This rule adds requirements for hybrid welding procedure qualification. Addition of this requirements to Paragraph QW-223 does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section IX of the ASME BPVC and therefore provide equivalent safety.
QW-290.3 Variables for Temper Bead Welding Qualifications	QW-290.3 was revised to state: Table QW-290.4 lists the additional essential, supplementary essential, and nonessential variables that apply when temper bead qualification is required. Essential variables column A shall apply when the applicable Construction Code or Design Specification specifies hardness criteria for temper bead acceptance criteria. Column B shall apply when the applicable Construction Code or Design Specification specifies toughness testing for temper bead acceptance criteria. Column C shall apply when the applicable Construction Code or Design Specification specifies neither hardness nor toughness test criteria. The column “Nonessential Variables” applies in all cases.	This rule adds requirements to column C in Table QW-290.4 Welding Variables for Temper Bead Procedure Qualification to be applied where maximum hardness or toughness testing is not specified in the either the construction code or design specification. Addition of this requirements to Paragraph QW-290.3 does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section IX of the ASME BPVC and therefore provide equivalent safety.
QW-420 Base Metal Groupings	QW-420 was revised to state: P-Numbers are assigned to base metals for the purpose of reducing the number of welding and brazing procedure qualifications required.	This revision adds requirements for P-Number material groups. In the 2009 Addenda, S-Number base metals listed in the QW/QB 422 table were reassigned as P-Numbers and the S-Number listings and references were deleted. Addition of this requirements to Paragraph QW-420 does not violate the fundamental safety assumptions stated or implied in the 2007

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section IX of the ASME BPVC	Equivalent Safety Evaluation
		edition of Section IX of the ASME BPVC and therefore provide equivalent safety.
Table QW/QB 422 Ferrous and Nonferrous P-Numbers Grouping of Base Metals for Qualification	The title of Table QW/QB 422 in the 2021 editions was revised to: Ferrous and Nonferrous P-Numbers Grouping of Base Metals for Qualification. In addition: (1) Second column head revised. (2) “AWS B2.2M” column was added. (3) Entries were revised. (4) Rows were added. (5) Rows were deleted.	This revision to Table QW/QB 422 eliminates S-Number listings, adds P-Number listings, revises entries, deletes rows, and changes the table format. Addition of this revision to Table QW/QB 422 does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section IX of the ASME BPVC and therefore provide equivalent safety.
QW-423 Alternate Base Materials for Welder Qualification	QW-423.1 was revised to state: Base metal used for welder qualification may be substituted for the base metal specified in the WPS in accordance with the following table. Any base metal shown in the same row may be substituted in the performance qualification test coupon for the base metal(s) specified in the WPS followed during welder qualification. When a base metal shown in the left column of the table is used for welder qualification, the welder is qualified to weld all combinations of base metals shown in the right column, including unassigned metals of similar chemical composition to these metals.	This revision adds rules to permit use of P-No. 15E and P-No. 15F base metals as alternate base materials for welder qualification. Addition of this revision to Paragraph QW-423.1 does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section IX of the ASME BPVC and therefore provide equivalent safety.
QW-424 Base Metals Used for Procedure Qualification	QW-424.2 was added to state: For welds joining base metals to weld metal buildup or corrosion-resistant weld metal overlay, the buildup or overlay portion of the joint may be substituted in the test coupon by any P-Number base material that nominally matches the chemical analysis of the buildup or overlay.	This revision adds requirements for joining base metals to weld metal buildup or corrosion-resistant weld metal overlay. Addition of this requirements to Paragraph QW-424.2 does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section IX of the ASME BPVC and therefore provide equivalent safety.
Part QF – Plastic Fusing	Part QF was added. Articles in Part QF include: Article XXI Plastic Fusing General Requirements Article XXII Fusing Procedure Qualifications Article XXIII Plastic Fusing Performance Qualifications Article XXIV Plastic Fusing Data	This addition of Part QF adds rules for plastic fusing to Section IX. Addition of Part QF does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section IX of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix A – Submittal of Technical Inquiries to	Mandatory Appendix A was deleted from the 2019 edition.	The 2021 edition includes Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees as part of the front matter in Section IX.

Paragraph	Rules and Requirements Revised or Added to the 2021 edition of Section IX of the ASME BPVC	Equivalent Safety Evaluation
the Boiler and Pressure Vessel Committee		
Nonmandatory Appendix H Waveform Controlled Welding	Nonmandatory Appendix H was added. H-100 Background states: Advances in microprocessor controls and welding power source technology have resulted in the ability to develop waveforms for welding that improve the control of droplet shape, penetration, bead shape and wetting. Some welding characteristics that were previously controlled by the welder or welding operator are controlled by software or firmware internal to the power source. It is recognized that the use of controlled waveforms in welding can result in improvements in productivity and quality. The intention of this Code is to enable their use with both new and existing procedure qualifications.	This addition of Nonmandatory Appendix H adds guidance for waveform-controlled welding. Addition of Nonmandatory Appendix H does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section IX of the ASME BPVC and therefore provide equivalent safety.
Mandatory Appendix J Guideline for Requesting P-Number Assignments for Base Metals not Listed in Table QW/QB-422	Mandatory Appendix J was added. J-100 Introduction states: This Mandatory Appendix provides requirements to Code users for submitting requests for P-Number assignments to base metals not listed in Table QW/QB-422.	This addition of Mandatory Appendix J adds rules for requesting P-Number assignments for base metals not listed in Table QW/QB-422. Addition of Mandatory Appendix J does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section IX of the ASME BPVC and therefore provide equivalent safety.
Nonmandatory Appendix K Guidance on Invoking Section IX Requirements in Other Codes, Standards, Specifications, and Contract Documents	Nonmandatory Appendix K was added. K-100 Background and Purpose states: The purpose of this Nonmandatory Appendix is to provide guidance on invoking Section IX in other documents in a clear, concise, and accurate manner.	This addition of Nonmandatory Appendix K adds guidance on invoking Section IX requirements in other codes, standards, specifications, and contract documents. Addition of Nonmandatory Appendix K does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section IX of the ASME BPVC and therefore provide equivalent safety.
Nonmandatory Appendix L Welders and Welding Operators Qualified Under ISO 9606-1:2012 and ISO 14732-2013	Nonmandatory Appendix L was added. L-100 Introduction states: This Appendix discusses what is necessary for an organization that is testing welders or welding operators under the above ISO standards to also certify that those welders and welding operators are qualified to Section IX.	This addition of Nonmandatory Appendix L provides discussions about what is necessary for an organization that is testing welders or welding operators under requirements of ISO 9606-1:2012 and ISO 14732:2013 to also certify that those welders and welding operators are qualified to Section IX. Addition of Nonmandatory Appendix L does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section IX of the ASME BPVC and therefore provide equivalent safety.

10. POST-CONSTRUCTION CODES AND STANDARDS

Rules for design and fabrication of boilers and pressure vessels specified in the ASME BPVC do not apply after the Manufacturer (Certificate Holder) applies the ASME Certification Mark (Code Stamp). Therefore, installation, inspection, maintenance, operation, repair, alterations, and replacement activities performed after a boiler or pressure vessel is placed in service are beyond the scope of the ASME BPVC. Codes and standards that establish rules for these activities are published by the:

- National Board of Boiler and Pressure Vessel Inspectors
- American Petroleum Institute
- American Society of Mechanical Engineers

10.1 NATIONAL BOARD OF BOILER AND PRESSURE VESSEL INSPECTORS

The National Board of Boiler and Pressure Vessel Inspectors was created in 1919 to promote greater safety to life and property through uniformity in the construction, installation, repair, maintenance, and inspection of pressure equipment. The National Board (NB) membership oversees adherence to laws, rules, and regulations relating to boilers and pressure vessels. Its members are the chief boiler inspectors representing most states and all provinces of Canada, as well as many major cities in the United States. The National Board's functions include:

- Promoting safety and educating the public and government officials on the need for manufacturing, maintenance, and repair standards.
- Offering comprehensive training programs in the form of continuing education for both inspectors and pressure equipment professionals.
- Enabling a qualified inspection process by commissioning inspectors through a comprehensive examination administered by the National Board.
- Setting worldwide industry standards for pressure relief devices and other appurtenances through operation of an international pressure relief testing laboratory.
- Providing a repository of Manufacturers' Data Reports through a registration process.
- Accrediting qualified repair and alteration companies, in-service Authorized Inspection Agencies, and owner-user inspection organizations.
- Investigating pressure equipment accidents and issues involving code compliance.
- Developing installation, inspection, repair, and alteration standards (i.e., National Board Inspection Code).

10.1.1 National Board Inspection Code

The National Board Inspection Code (NBIC) is an American National Standard (NB-23) [18] that has been adopted by most states and cities, all Canadian provinces, and Federal regulatory agencies including the DOT. It is the only standard recognized worldwide for in-service inspection repairs and alterations of boilers and pressure vessels.

The NBIC was first published in 1946 as a guide for chief inspectors. It has become an internationally recognized standard, adopted by most U.S. and Canadian jurisdictions. The NBIC provides standards for the installation, inspection, and repair and/or alteration of boilers, pressure vessels, and pressure relief devices. The NBIC is organized into three parts to coincide with specific post-construction activities involving pressure-retaining items.

Part 1, *Installation* – Part 1 provides requirements and guidance to ensure all types of pressure-retaining items are installed and function properly. Installation includes meeting specific safety criteria for construction, materials, design, supports, safety devices, operation, testing, and maintenance.

Part 2, *Inspection* – Part 2 provides information and guidance needed to perform and document inspections for all types of pressure-retaining items. This Part includes information on personnel safety, non-destructive examination, tests, failure mechanisms, types of pressure equipment, fitness for service, risk-based assessments, and performance-based standards.

Part 3, *Repairs and Alterations* – Part 3 provides information and guidance to perform, verify, and document acceptable repairs or alterations to pressure-retaining items regardless of code of construction. Alternative methods for examination, testing, heat treatment, etc., are provided when the original code of construction requirements cannot be met. Specific acceptable and proven repair methods are also provided.

It is important to note that:

- Part 1 of the NBIC provides a method for ensuring that pressure relief devices for boilers and pressure vessels required by the applicable ASME BPVC section for overpressure protection are installed prior to placing the boiler and pressure vessel in service.
- Part 2 of the NBIC provides a method for ensuring that pressure relief devices for boilers and pressure vessels required by the applicable ASME BPVC section for overpressure protection are periodically inspected and tested while the boiler or pressure vessel is in service. Part 2 of the NBIC also provides a method for ensuring that boilers and pressure vessels are fit for service after inspection reveals that the boiler or pressure vessel has experienced damage or degradation while in service.
- Part 3 of the NBIC provides a method for ensuring that boilers and pressure vessels comply with applicable ASME BPVC rules following repairs or alterations.

The NBIC is developed and maintained by a consensus committee (the NBIC Main Committee) and updated every other year. The updates are presented on the National Board's website for public review in August of the year prior to the edition date. The NBIC is published as a new edition in July of odd numbered years (2019, 2021, etc.).

10.1.2 National Board Registration

The National Board also registers pressure vessels that are constructed in accordance with the ASME BPVC. Registration of an item with the National Board involves the manufacturer submitting an original manufacturer's data report to the National Board for permanent retention. Registration is more than record retention; it represents the culmination of a three-step process, including the design and fabrication of an item in accordance with the ASME BPVC, the inspection by a National Board commissioned inspector, and the final documentation certifying compliance with the ASME BPVC.

Compliance with 49 CFR Part 193 requires registration of pressure vessels for LNG facilities that are designed and fabricated in accordance with rules specified in Section VIII of the ASME BPVC through the IBR process. Requirements for registration of pressure vessels for LNG facilities that are designed and fabricated in accordance with rules specified in Section VIII of the ASME BPVC are specified in Paragraph 10.3.4 in the 2001 edition of NFPA 59A.

10.2 AMERICAN PETROLEUM INSTITUTE

The API has adopted API 510 – Pressure Vessel Inspection Code: In-service Inspection, Rating, Repair, and Alteration [19]. This standard covers in-service inspection, repair, alteration, and rerating activities for pressure vessels and the pressure-relieving devices protecting these pressure vessels. It applies to all hydrocarbon and chemical process vessels that have been placed in service unless specifically excluded per 1.2.2; but it could also be applied to process vessels in other industries at owner/user discretion. This includes pressure vessels constructed in accordance with an applicable Construction Code (e.g., ASME BPVC).

Paragraph 1.1.1 in API 510 states:

> *ASME BPVC and other recognized Construction Codes are written for new construction; however, most of the technical requirements for design, welding, NDE, and materials can be applied to the inspection, rerating, repair, and alteration of in-service pressure vessels. If for some reason an item that has been placed in service cannot follow the Construction Code because of its new construction orientation, the requirements for design, material, fabrication, and inspection shall conform to API 510 rather than to the Construction Code. If in-service vessels are covered by requirements in the Construction Code and API 510 or if there is a conflict between the two codes, the requirements of API 510 shall take precedence.*

As an example of the intent of API 510, the phrase "applicable requirements of the Construction Code" has been used in API 510 instead of the phrase "in accordance with the Construction Code." Paragraph 6.2.1.1 in API 510 further states that inspection activities during pressure vessel installation must include verification that the pressure-relieving devices satisfy design requirements (correct device and correct set pressure) and are properly installed.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. In May 2014, API published the tenth edition of API 510. The ninth edition of API 510 has been adopted by PHMSA in 49 CFR Part 195 through the IBR process discussed in Sect. 1.2 of this report. However, API 510 has not been adopted by PHMSA into Federal pipeline safety standards (i.e., 49 CFR Parts 192 and 193) through the IBR process.

10.3 FITNESS-FOR SERVICE, API 579-1/ASME FFS-1

Rules for design, fabrication, inspection and testing of new boilers, pressure vessels, piping systems, and storage tanks are provided in Construction Codes and standards published by API and ASME. These codes and standards typically do not provide rules for evaluating equipment that degrades while in-service and deficiencies caused by degradation or from original fabrication defects that are found during subsequent post-construction inspections. Ensuring that boilers and pressure vessels remain fit for service requires periodic inspections and fitness-for-service (FFS) assessments of pressure-retaining items that do not conform to rules specified in the original code of construction. The NBIC (NB-23) and the API pressure vessel inspection code (API 510) discussed in Sects. 10.1.1 and 10.2 of this report provide rules for post-construction inspection of boilers and pressure vessels. Rules for assessing FFS are provided in API 579-1/ASME FFS-1 published jointly by API and ASME.

Fitness-for-service (FFS) standard API 579-1/ASME FFS-1 [9] provides procedures for FFS assessments and rerating of equipment designed and fabricated to the following codes:

- ASME BPVC, Section I
- ASME BPVC, Section VIII, Division 1
- ASME BPVC, Section VIII, Division 2

These FFS assessments are quantitative engineering evaluations that are performed to demonstrate the structural integrity of an in-service component that may contain a flaw or damage, or that may be operating under a specific condition that might cause a failure. This standard provides guidance for conducting FFS assessments using methodologies specifically prepared for pressurized equipment. The guidelines provided in this standard can be used to make run-repair-replace decisions to help determine if components in pressurized equipment containing flaws that have been identified by inspection can continue to operate safely for some period. These FFS assessments are currently recognized and referenced by the NB-23 [18] and API 510 [19] as suitable means for evaluating the structural integrity of boilers and pressure vessels where inspection has revealed degradation and flaws in the equipment. However, the National Board Inspection Code (NBIC) and the Fitness-for-service (FFS) standard API 579-1/ASME FFS-1 have not been adopted by PHMSA into Federal pipeline safety standards (i.e., 49 CFR Parts 192, 193, and 195) through the IBR process.

11. EQUIVALENT SAFETY EVALUATION SUMMARY AND OBSERVATIONS

Currently, all or parts of more than 60 standards and specifications developed and published by standard developing organizations have been incorporated by reference into Federal pipeline safety regulations. The specific codes and standards published by ASME, NFPA, and API that are incorporated by reference into 49 CFR Parts 192, 193, and 195 are shown in Tables 1.3 through 1.5 of this report.

In general, standards developing organizations update and revise their standards every 2 to 5 years to incorporate modern technology and best technical practices. However, the ASME BPVC editions shown in Tables 1.3 through 1.5 were published in 2007. Therefore, they no longer current because the ASME BPVC is published every other year (i.e., 2019, 2021, etc.) on July 1. Compliance with the ASME BPVC editions shown in Tables 1.3 through 1.5 requires satisfying requirements that are obsolete which means:

- a new boilers or pressure vessel intended for use in a pipeline facility can only be assigned a Certification Mark with the appropriate Designator in accordance with rules specified in the current edition of Sections I, Section VIII, Division 1, or Section VIII, Section 2 of the ASME BPVC, as applicable.
- application of a Certification Mark or a Code symbol stamp for a boiler or pressure vessel constructed to a superseded edition of the ASME BPVC is not permitted as discussed in Sect. 1.3 of this report.

To the extent practicable, PHMSA ensures that pipeline safety regulations are consistent with safety requirements specified in IBR consensus codes and standards. Rationale and justification for concluding that requirements provided in the IBR editions of the ASME BPVC provide equal or greater safety to later editions of the ASME BPVC are documented in two reports.

The first report titled *ASME Boiler and Pressure Vessel Code Evaluation and Equivalence Study for Liquefied Natural Gas Facilities* [4] was prepared in 2017 to address risks associated with LNG facilities within the scope of 49 CFR Part 193. For this study, the safety baseline for comparison is the 1992 edition of the ASME BPVC.

This report uses a similar technical approach to conclude that the rules and requirements specified in the 2021 edition of the ASME BPVC provide equal or greater safety for boilers and pressure vessels in pipeline facilities compared to corresponding rules and requirements specified in the 2007 editions of the ASME BPVC.

As discussed in Sect. 1.4 of this report, the safety equivalency determinations described in these reports are based on either qualitative or quantitative comparative analysis results in which the safety consequences and potential benefits of the requirements changes are assessed and the technical rationale for determining whether the changes do, or do not, result in equivalent safety are documented.

11.1 EQUIVALENT SAFETY EVALUATION SUMMARY

This report documents the comparative analysis results that provides rationale and justification for concluding that the rules and requirements specified in Section I; Section VIII, Division 1; and Section VIII, Division 2 in the 2021 edition of the ASME BPVC are equivalent in safety to the corresponding rules and requirements specified in Section I; Section VIII, Division 1; and Section VIII, Division 2 in the 2007 edition of the ASME BPVC.

Equivalency evaluation results presented in this report focus primarily on materials; design including failure modes, strength theories, and principles of limit design theory; fabrication and inspection including nondestructive examinations; pressure testing; and overpressure protection.

11.1.1 Equivalent Safety Evaluation for Materials

Section II of the ASME BPVC is a Reference Code that defines requirements for materials permitted for construction of boilers and pressure vessels that comply with rules specified in Construction Codes (i.e., Section I; Section VIII, Division 1; and Section VIII, Division 2). It includes material specifications in Parts A, B, and C and material properties in Part D.

From time-to-time addition or removal of material specifications from Section II becomes necessary when the specification has either been replaced with another specification or there is no known production or use of a material. Addition or removal of a specification from Section II also results in concurrent addition or removal of the specification from Section IX and the Construction Code that references the material.

Material specifications that have been added to or removed from the 2021 edition of Section II since the 2007 edition was published are listed in Tables 3.1 through 3.4 of this report. These material specification changes do not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.

Changes to Part D in the 2021 edition of Section II include addition of Mandatory Appendix 6 – Basis for Establishing Stress Values in Tables 6A, 6B, 6C, and 6D. These allowable stress values apply to materials used to construct heating boilers in accordance rules specified in Section IV of the ASME BPVC and are included for information only. Addition of Mandatory Appendix 6 does not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section II of the ASME BPVC and therefore provide equivalent safety.

11.1.2 Equivalent Safety Evaluation for Design

Design rules and requirements in the ASME BPVC are provided to ensure that a boiler or pressure vessel will provide safe and satisfactory performance during its useful service life. However, compliance with these rules and requirements does not ensure a long service life nor does it guarantee a minimum design margin when the loadings and environmental conditions are more severe than those represented in the design basis. Design criteria in Section I; Section VIII, Division 1; and Section VIII, Section 2 of ASME BPVC are provided to prevent the following possible modes of failure.

- Excessive elastic deformation including elastic instability
- Excessive plastic deformation (ductile rupture)
- Brittle fracture
- Stress rupture / creep deformation (inelastic)
- Plastic instability – incremental collapse
- High strain – low-cycle fatigue
- Stress corrosion
- Corrosion fatigue

The minimum lateral expansion values for Charpy-V notch specimens permitted in the 2021 edition for materials listed in Table 3-A.1 –Carbon and Low Alloy Steel Materials Except Bolting Materials are approximately 30% greater than the minimum lateral expansion values permitted in the 2007 edition of

Section VIII, Division 2 of the ASME BPVC. Consequently, toughness requirements in the 2021 edition of Section VIII, Division 2 of the ASME BPVC for materials listed in Table 3-A.1 are more stringent than those in the 2007 edition for materials listed in Table 3-A.1.

Comparison of differences and similarities in design criteria between the 2007 and 2021 editions of the ASME BPVC Construction Codes are presented in Table 4.14 of this report. Results of these comparisons serve as input to evaluation of equivalent safety for design rules and requirements specified in the 2007 and 2021 editions. The evaluations of equivalent safety for design rules and requirements are documented in Tables 9.1 through 9.4, 9.7, and 9.8 of this report. These evaluation results support the conclusion that design rules and requirements specified in the 2021 edition of ASME BPVC:

- provide equivalent safety compared to design rules and requirements specified in the 2007 edition of ASME BPVC.
- do not violate the fundamental safety assumptions stated or implied in the 2007 edition of the ASME BPVC and therefore provide equivalent safety.

11.1.3 Equivalent Safety Evaluation for Fabrication

Boiler and pressure vessel fabrication often involve a broad range of manufacturing methods and processes such as forming, machining, bolting, welding, brazing, and heat treating. These methods and processes tend to change as construction technology evolves and improves over time. However, no organization may assume responsibility for BPVC construction without having first received from the ASME a Certificate of Authorization to use the Certification Mark and Designators. According to rules specified in the 2021 edition of Section I; Section VIII, Division 1; and Section VIII, Section 2 of ASME BPVC, any Manufacturer holding or applying for a Certificate of Authorization must demonstrate a Quality Control System that meets the requirements of *Conformity Assessment Requirements* in ASME CA-1 [2]. This rule was not specified in the 2007 edition of the ASME BPVC because ASME CA-1 was initially published after the 2007 edition was issued.

Rules specified in Section I; Section VIII, Division 1; and Section VIII, Section 2 of ASME BPVC for boiler and pressure vessel fabrication have been revised and updated since the 2007 edition was published. Equivalent safety evaluations of these rule changes are detailed in Tables 9.1 through 9.4, 9.7, and 9.8 of this report. Results of these evaluations show that these rule changes do not violate the fundamental safety assumptions stated or implied in the 2007 edition of the ASME BPVC and therefore provide equivalent safety.

11.1.4 Equivalent Safety Evaluation for Inspections, Tests, and Examinations

The ASME BPVC provides requirements for inspections, tests, and examinations including nondestructive examinations of boilers and pressure vessels. Section V – Nondestructive Examination of the ASME BPVC describes methods and requirements for nondestructive examination (NDE) used to detect surface and internal imperfections in boiler and pressure vessel materials, welds, fabricated parts, and components. Advancements in NDE technologies since the 2007 edition was issued are discussed in Sect. 6.3 of this report.

Rules for certification of NDE personnel are specified in Paragraph T-120*(e)* in the 2021 edition of Section V of the ASME BPVC. These rules state that the qualification must be in accordance with the employer's written practice that complies with one of the following documents:

(1) SNT-TC-1A, Personnel Qualification and Certification in Nondestructive Testing (2016 edition); or

(2) ANSI/ASNT CP-189, ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel (2016 edition).

By comparison, Paragraph T-120*(e)* in the 2007 edition of Section V of the ASME BPVC requires compliance with the 2001 editions of SNT-TC-1A and ANSI/ASNT CP-189.

Paragraph UW-54 in the 2021 editions of Section VIII, Division 1 and Paragraph 7.3 in the 2021 edition of Section VIII, Division 2 require compliance with rules specified in Paragraph T-120*(e)* in the 2021 edition of Section V of the ASME BPVC. However, Paragraph PW-50 in the 2021 edition of Section I requires compliance with the 2006 editions of SNT-TC-1A and ANSI/ASNT CP-189. Table 6.6 of this report maps paragraphs in Section I; Section VIII, Division 1; and Section VIII, Division 2 that provide qualification and certification requirements for NDE personnel to sections referenced in this report where these qualification and certification requirements are examined and explained.

Although NDE technologies have advanced and guidance in SNT-TC-1A and ANSI/ASNT CP-189 has been updated since 2001, rules in the 2021 edition of the ASME BPVC for certification of NDE personnel do not violate the fundamental safety assumptions stated or implied in the 2007 edition of the ASME BPVC and therefore provide equivalent safety.

11.1.5 Equivalent Safety Evaluation for Testing

Section I and Section VIII, Division 2 in the 2007 and 2021 editions of the ASME BPVC specify limits for maximum primary stresses that occur during pressure testing. These primary stress limits ensure that the boiler or pressure vessel remains below the plastic collapse stress limit. Corresponding primary stress limits are not specified in Section VIII, Division 1 for hydrostatic and pneumatic tests. Instead, any visible permanent distortion that occurs during pressure testing could result in rejection of the pressure vessel by the Inspector.

A comparison of pressure testing requirement specified in the 2007 and 2021 editions of the ASME BPVC is presented in Table 7.4 of this report. These pressure testing requirements are discussed further in Sects. 7.1.1, 7.1.2, and 7.1.3 of this report. Except for the minimum hydrostatic pressure test limit specified in the 2007 edition of Section VIII, Division 2 of the ASME BPVC, the pressure testing requirements are the same. Based on these comparisons, pressure testing requirement in the 2021edition of the ASME BPVC do not violate the fundamental safety assumptions stated or implied in the 2007 edition of Section VIII, Division 2 of the ASME BPVC and therefore provide equivalent safety.

From a safety viewpoint, alternative pressure testing and proof testing rules specified in the 2007 and 2021 editions of the ASME BPVC are the same. Therefore, rules for alternative pressure testing and proof testing do not violate the fundamental safety assumptions stated or implied in the 2007 edition of the ASME BPVC and therefore provide equivalent safety.

11.1.6 Equivalent Safety Evaluation for Overpressure Protection

Section I requirements formerly in PG-69.1.2; PG-69.1.3; PG-69.1.5; PG-69.2.1 through PG-69.2.6; PG-69.6; and Nonmandatory Appendix A, A-311, have been transferred to Section XIII – Rules for Overpressure Protection, Part 9 – Capacity and Flow-Resistance Certification. Table G-1-1 – Cross-Reference List in Nonmandatory Appendix G – Guide to the Relocation of Requirements for Capacity Certification of Pressure Relief Valves in Section I lists the new locations for these requirements. Overpressure protection rules specified in Paragraph PG-67.4.2 in the 2007 and 2021 editions of Section I of the ASME BPVC limit the pressure of an operating boiler, except for the steam piping between the boiler and the prime mover, to 1.20 MAWP or less. This overpressure protection limit ensures that the primary membrane stress, P_m, does not exceed $0.80S_y$ (i.e., $1.20/1.50$). The rules for overpressure protection specified in the 2007 and 2021 editions of Section I of the ASME BPVC are the same. Therefore, the rules for overpressure protection specified in the 2021 edition of Section I of the ASME BPVC provide an equivalent level of safety compared to the rules for overpressure protection specified in the 2007 edition of Section I of the ASME BPVC.

All Section VIII, Division 1 pressure relief device requirements have been transferred from Paragraphs UG-125 through UG-140 to Section XIII – Rules for Overpressure Protection and the remaining Division 1 overpressure protection requirements have been restructured within the new Paragraphs UG-150 through UG-156. Table PP-1-1 in Nonmandatory Appendix PP lists the new locations for all requirements formerly located in UG-125 through UG-140. Section XIII was introduced into the ASME BPVC in the 2021 edition. Paragraph UG-150*(a)* in the 2021 edition of Section VIII, Division 1 states: UG-150 through UG-155 provide the acceptable methods and requirements for overpressure protection for pressure vessels constructed to the requirements of this Division. Acceptable methods include pressure relief devices, open flow paths (Note: flow path rules are not included in the 2007 edition), and overpressure protection by system design (Note: overpressure protection by system design rules are not included in the 2007 edition). Paragraph UG-154*(e)* specifies rules for overpressure protection by system design in accordance with Section XIII, Part 13 when permitted. However, due to restructuring of paragraphs in the 2021 edition and transferring to Section XIII, a comprehensive equivalent safety evaluation of overpressure protection rules between the 2007 and 2021 edition of Section VIII, Division 1 of the ASME BPVC was not performed.

All Section VIII, Division 2 pressure relief device requirements have been transferred from Part 9 – Pressure Vessel Overpressure Protection to Section XIII – Rules for Overpressure Protection and the remaining Division 2 overpressure protection requirements have been restructured within Part 9. Annex 9-B – Guide to the Relocation of Overpressure Protection Requirements provides a complete cross-reference list in Table 9-B.1-1 – Cross-Reference List. Requirements in Part 9 provide the acceptable methods and requirements for overpressure protection for pressure vessels constructed to the requirements of this Division. Paragraph 9.5 – Permitted Pressure Relief Devices and Methods states that protection against overpressure shall be provided by pressure relief devices, open flow paths or system design, or a combination. Paragraph 9.5*(e)* permits protection by system design in accordance with requirements provided in Section XIII, Part 13 when permitted. However, due to restructuring of paragraphs in the 2021 edition and transferring to Section XIII, a comprehensive equivalent safety evaluation of overpressure protection rules between the 2007 and 2021 edition of Section VIII, Division 2 of the ASME BPVC was not performed.

Section XIII – Rules for Overpressure Protection in the 2021 edition of the ASME BPVC provides rules for the overpressure protection of pressurized equipment such as boilers, pressure vessels, and piping systems. This standard provides requirements for topics such as design, material, inspection, assembly, testing, and marking for pressure relief valves, rupture disk devices, pin devices, spring-actuated non-reclosing devices, and temperature and pressure relief valves. This standard also covers devices in combination, capacity and flow resistance certification, authorization to use the ASME Certification Mark, installation, and overpressure protection by system design. As a Reference Code, rules specified in Section XIII are only mandatory when referenced from a Construction Code.

11.2 OBSERVATIONS FOR ENHANCING THE SAFETY OF BOILER AND PRESSURE VESSELS IN PIPELINE FACILITIES

The ASME Boiler and Pressure Vessel Committee's function is to establish rules of safety relating only to pressure integrity which govern the construction of boilers and pressure vessels. However, these rules no longer apply after the boiler or pressure vessel has been placed in service.

After a boiler or pressure vessel has been placed in service, degradation of the pressure boundary components can occur. Common types of degradation that can adversely affect the structural integrity of a boiler or pressure vessel include metal loss caused by corrosion or erosion, physical damage caused by cracking or fatigue, and material damage caused by changes in operating conditions or service environments. Detecting and evaluating in-service degradation may be necessary to ensure that the boiler or pressure vessel remains consistent with PHMSA safety objections.

Consensus post-construction standards with requirements for performing in-service inspections and fitness-for-service assessments of boilers and pressure vessels include:

(1) American National Standard NB-23 – National Board Inspection Code [18] (See Sect. 10.1 of this report.)
(2) API Standard 510 – Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair, and Alteration [19] (See Sect. 10.2 of this report.)
(3) API 579-1/ASME FFS-1, Fitness-for-Service (FFS) [9] (See Sect. 10.3 of this report.)

Based on a review of IBR standards in 49 CFR 192, 193, and 195 that apply to boilers and pressure vessels:

- 49 CFR 192 and 193 do not require in service inspections in accordance with American National Standard NB-23 – National Board Inspection Code or API Standard 510.
- 49 CFR 195 incorporates by reference API Standard 510 but not American National Standard NB-23 – National Board Inspection Code.
- 49 CFR 192, 193, and 195 do not require fitness-for-service assessments in accordance with API 579-1/ASME FFS-1.

In-service inspections and fitness-for-service assessments in accordance with these post-construction consensus standards could potentially enhance the safety of boilers and pressure vessels in pipeline facilities because in-service inspection and fitness-for-service assessment results offer a sound basis for decisions to continue to run as is or to alter, repair, monitor, retire, or replace the equipment.

12. REFERENCES

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APPENDIX A – HISTORICAL PERSPECTIVE: DESIGN STRESSES

APPENDIX A
HISTORICAL PERSPECTIVE: DESIGN STRESSES

The following text is published in a book by Martin D. Bernstein and Lloyd W. Yoder titled: *Power Boilers – A Guide to Section I of the ASME Boiler and Pressure Vessel Code* [14]. It presents a historical perspective on the evolution of design stresses used in the ASME BPVC through 1998.

> *The so-called safety factors, or design margins, now used in establishing allowable stresses with respect to the various failure modes, such as yielding or creep rupture, have evolved over the life of the Code. Before World War II the factor used on tensile strength was 5. It was changed to 4 in order to save steel during the war. Starting in the late 1970s, the factor on yield strength was changed from 5/8 to 2/3, a change that was carried out over quits a long period. The factor on the 100,000-hour creep rupture strength was formerly 0.6. Around 1970, this was changed to the current factor of 0.67. These reductions in design margins, or safety factors, were adopted over time as improvements in technology permitted. These improvements included the development of newer and more reliable methods of analysis, design, and nondestructive examination. The imposition of quality control systems in 1973 and a record of long satisfactory experience also helped justify reducing some of the design conservatism.*
>
> *One of the design factors the ASME uses in setting allowable stress not used by most other countries is the factor of approximately 4 on ultimate tensile strength. It happens that this design factor is a significant one, because it controls the allowable stress for many ferritic (carbon and low alloy) steels below the creep range. This has put users of the ASME Code at a disadvantage in world markets where competing designs are able to utilize higher allowable stresses based just on yield strength. This situation has caused the Code committees to reconsider the usefulness and necessity of using tensile strength as one of the criteria for setting allowable stress. In 1996 the Pressure Vessel Research Council (PVRC), a research group closely associated with the Code committees, was asked to study whether the design factor on tensile strength could safely be reduced. The PVRC prepared a report reviewing all the technological improvements in boiler and pressure vessel construction that have occurred since the early 1940s, which was when the design factor on tensile strength was last reduced, from 5 to 4. On the basis of that report's favorable recommendation, Subcommittee VIII has decided, as an initial step, to change the factor on tensile strength from about 4 to about 3.5 for pressure vessels constructed under the 1.43provisions of Section VIII, Division 1.*
>
> *Subcommittee I decided to make the same change for Section I and in 1997 established a task group to investigate the potential effects of such a change and how best to implement it. That task group concluded that Section I could safely join Section VIII in increasing its allowable stresses. The actual mechanics of setting and publishing new allowable stresses took Subcommittee II some time, because it was quite a task. In order to expedite the process while Subcommittee II completed its work, new stresses for a limited group of materials were introduced by means of Code cases, one for Section I and two for Section VIII, since Code cases can be issued far more quickly than Code Addenda. The Section I case is Case 2284, Alternative Maximum Allowable Stresses for Section I Construction Based on a Factor of 3.5 on Tensile Strength. The three cases were approved for use in mid-1998, and their higher stress values are expected to be incorporated into Section II, Part D in the near future, perhaps in the 1999 Addenda. One problem with the new cases is that some jurisdictions were reluctant to accept them, or had no ready mechanism which would permit their prompt adoption. Thus widespread use of the higher stresses may have to await their incorporation into Section II, Part D.*
>
> *In the future, it is possible that the design factor on tensile strength may be reduced further or eliminated altogether, depending on the results of these first steps. Note that the change in design*

factor applied to tensile strength from 1/4 to 1/3.5 is a 14% change. However few allowable stresses will change that much, because the higher allowable stress will probably be determined and controlled by the factor applied to yield strength, rather than tensile strength. Also note that the higher stresses will be applicable below the creep range only.

The above-described methods of setting maximum allowable (design) stress values have been used by the Code committees since the mid-1950s. During that time, new data have been obtained and analyzed to revise design stresses as appropriate, based both on new laboratory tests and reported experience from equipment in service. There have been times when the analysis of new data has resulted in a significant lowering of the allowable stresses at elevated temperature. In all but a few instances, however, the fine safety record of equipment built to the ASME Code has demonstrated the validity of the material data evaluation, design criteria, and design methods used.