ASME BPVC.X-2025

SECTION X

2025

ASME Boiler and Pressure Vessel Code

An International Code

Fiber-Reinforced Plastic Pressure Vessels

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AN INTERNATIONAL CODE

2025 ASME Boiler & Pressure Vessel Code

2025 Edition July 1, 2025

X

FIBER-REINFORCED PLASTIC PRESSURE VESSELS

ASME Boiler and Pressure Vessel Committee
on Fiber-Reinforced Plastic Pressure Vessels

The American Society of Mechanical Engineers

Two Park Avenue • New York, NY • 10016 USA

Date of Issuance: July 1, 2025

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FOREWORD*

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 In 2009, the Boiler and Pressure Vessel Committee was superseded by the following committees:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Revisions and Errata

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

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

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

Cases

(a) The most common applications for cases are

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

(2) to provide alternative requirements

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

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

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

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

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

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

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

(1) a statement of need and background information

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

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

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

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

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

Interpretations

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

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

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

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

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

Committee Meetings

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

INTRODUCTION

1 GENERAL

The use of fiber-reinforced plastics for the manufacture of pressure vessels presents unique materials considerations in the design, fabrication, and testing of these vessels. Metallic vessels, being made from materials that are normally isotropic and ductile, are designed by using well-established allowable stresses based on measured tensile and ductility properties. In contrast, fiber-reinforced plastics are usually anisotropic and the physical properties are dependent upon the fabrication process, the placement and orientation of the reinforcement, and the resin matrix. It is the purpose of this Introduction to describe in a general way the criteria that were used in preparing Section X, Fiber-Reinforced Plastic Pressure Vessels. A list of standards referenced in this Section is provided in Table 1.1.

2 MATERIALS

It is not possible to fabricate a reinforced plastic pressure vessel of a single basic material for which there is an ASTM specification. The vessel parts are made up of various basic materials, such as fiber reinforcement and resin, which are joined in the presence of a catalyst to create a composite material that is formed into a vessel or vessel part by a specified process. The composite material will often have directional properties, which shall be considered in design. General specifications for the basic materials (fiber reinforcement and resin) are stated, as are requirements for determination of elastic properties for the composite material (laminate) produced. Elastic properties of specific laminates used in vessel fabrication are required when mandatory rules are used for vessel design. Metallic materials, when used in conjunction with reinforced fiber laminates, are required to meet ASME Boiler and Pressure Vessel Code specifications, Section VIII, Division 1. That Section must be used for the design, fabrication, quality control, and inspection of such metallic parts. However, for hydrostatic leakage testing, these metallic materials that complete the vessel are required to meet Section X requirements.

3 DESIGN

3.1 GENERAL

3.1.1 Adequacy of specific designs shall be qualified by one of the following methods:[1]

(a) Class I Design — qualification of a vessel design through the pressure testing of a prototype.

(b) Class II Design — mandatory design rules and acceptable testing by nondestructive methods.

(c) Class III Design—qualification of a vessel design through the pressure testing of a prototype, other specified tests of prototypes, mandatory design rules and acceptance testing by nondestructive methods.

3.1.2 Class I designs based on the qualification of a prototype vessel require that the minimum qualification pressure of the prototype be at least six[2] times the design pressure. The maximum design pressure is limited to 150 psi (1 MPa) for bag-molded, centrifugally cast, and contact-molded vessels; 1,500 psi (10 MPa) for filament-wound vessels; and 3,000 psi (20 MPa) for filament-wound vessels with polar boss openings.

3.1.3 Class II designs based on mandatory design rules and acceptance testing must comply with Article RD-11 and Article RT-6. The maximum design pressure allowed under this procedure shall be as specified in RD-1120.

3.1.4 Class III designs include the qualification of a prototype with the minimum qualification pressure of the prototype to be at 2.25 times the design pressure for carbon fiber vessels, and 3.5 times the design pressure for glass fiber vessels. Hybrid designs using more than one type of fiber are covered in 8-400.7. The maximum design pressure is limited to 15,000 psi (103 MPa). The minimum design pressure shall be not less than 3,000 psi (20.7 MPa).

[1] These three methods shall not be intermixed.

[2] An exception to this six times factor is applicable to vessels per (Filament Winding — Polar Boss Openings Only).

(25)

Table 1.1
Referenced Standards in This Section

Designator	Title	Edition Year
API 579-1/ASME FFS-1	Fitness-for-Service	2021
ASME B16.1	Cast Iron Pipe Flanges and Flanged Fittings	2020
ASME B16.5	Pipe Flanges and Flanged Fittings	2020
ASME B18.22.1	Plain Washers	2016
ASME CA-1	Conformity Assessment Requirements	2022
ASNT-CP-189	Standard for Qualification and Certification of Nondestructive Testing Personnel	2020
ASTM D445	Standard Test Method for Kinematic Viscosity and Opaque Liquids (the Calculation of Dynamic Viscosity)	2021
ASTM D638	Standard Test Method for Tensile Properties of Plastics	2022
ASTM D695	Standard Test Method for Compressive Properties of Rigid Plastics	2023
ASTM D792	Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement	2020
ASTM D1045	Standard Test Methods for Sampling and Testing Plasticizers Used in Plastics	2019
ASTM 1180	Method of Test for Bursting Strength of Round Rigid Plastic Tubing	1977
ASTM D1652	Standard Test Methods for Epoxy Content of Epoxy Resins	2011
ASTM D2196	Standard Test Methods for Rheological Properties of Non-Newtonian Materials by Rotational Viscometer	2020
ASTM D2290	Standard Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe	2019
ASTM D2343	Standard Test Method for Tensile Properties of Glass Strands, Yarns, and Rovings Used in Reinforced Plastics	2017
ASTM D2344/D2344M	Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates	2022
ASTM D2393	Standard Test Method for Epoxy Resins and Related Components	1986
ASTM D2471	Standard Test Method for Gel Time and Peak Exothermic Temperature of Reacting Thermosetting Resins	1999
ASTM D2583	Standard Test Method for Indentation Hardness of Rigid Plastics by Means of Barcol Impressor	2013
ASTM D2584	Standard Test Method for Ignition Loss of Cured Reinforced Resins	2018
ASTM D2585	Test Method for Preparation and Tension Testing of Filament-Wound Pressure Vessels	1968
ASTM D2992	Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass- Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings	2022
ASTM D3030	Standard Test Method for Volatile Matter (Including Water) of Vinyl Chloride Resins	2023
ASTM D3039/D3039M	Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials	2017
ASTM D3171	Standard Test Method for Constituent Content of Composite Materials	2022
ASTM D3410/D3410M	Standard Test Method for Compressive Properties for Polymer Matrix Composite Materials With Unsupported Gage Section by Shear Loading	2016
ASTM D3529	Standard Test Methods for Constituent Content of Composite Prepeg	2016
ASTM D3531/D3531M	Standard Test Method for Resin Flow of Carbon Fiber-Epoxy Prepreg	2016
ASTM D3846	Standard Test Method for In-Plane Shear Strength of Reinforced Plastics	2008
ASTM D4018	Standard Test Methods for Properties of Continuous Filament Carbon and Graphite Fiber Tows	2023
ASTM D4097	Standard Specification for Contact-Molded Glass-Fiber-Reinforced Thermoset Resin Corrosion-Resistant Tanks	2019
ASTM D4255/D4255M	Standard Guide for Testing In-Plane Shear Properties of Polymer Matrix Composite Materials by the Rail Shear Method	2020
ASTM D4814	Standard Specification for Automotive Spark-Ignition Engine Fuel	2023
ASTM D5448/D5448M	Standard Test Method for In-Plane Shear Properties of Hoop Wound Polymer Matrix Composite Cylinders	2022
ASTM D5449/D5449M	Standard Test Method for Transverse Compressive Properties of Hoop Wound Polymer Matrix Composite Cylinders	2022
ASTM D5450/D5450M	Standard Test Method for Transverse Tensile Properties of Hoop Wound Polymer Matrix Composite Cylinders	2022
ASTM D7078/D7078M	Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method	2020
ASTM D790	Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials	2017

Table 1.1
Referenced Standards in This Section (Cont'd)

Designator	Title	Edition Year
ASTM E1067/E1067M	Standard Practice for Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin (FRP) Tanks/Vessels	2018
ASTM E1316	Standard Terminology for Nondestructive Examinations	2023
ASTM E2478	Standard Practice for Determining Damage-Based Design for Fiberglass Reinforced Plastic (FRP) Materials Using Acoustic Emission	2011
ASTM G62	Standard Test Methods for Holiday Detection in Pipeline Coatings	2022
SNT-TC-1A	Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing	2020

3.2 LOW MODULUS CHARACTERISTICS

Fiber-reinforced plastic laminates may have a modulus of elasticity as low as 1.0×10^6 psi (6 900 MPa), compared with that of ferrous materials which may be of the order of 30×10^6 psi (2.1 × 105 MPa). This low modulus characteristic requires careful consideration of vessel profile in order to minimize bending and avoid buckling. Spherical heads or elliptical heads having an ellipse ratio not greater than 2:1 are suggested. Spherical heads are suggested when the material has isotropic properties. Elliptical heads are preferred when the material has anisotropic properties.

3.3 FATIGUE

3.3.1 Like metallic materials, the composite material (laminate) of fiber-reinforced plastic vessels, when stressed at sufficiently low levels, exhibits good fatigue life. However, its low modulus of elasticity provides a higher strain per unit of stress than metals used for metallic vessels.

3.3.2 Section X, therefore, requires that a Class I design that is qualified by testing of a prototype vessel be pressure cycled 100,000 times over a pressure range of atmospheric to the design pressure; after this, the test vessel must withstand a hydrostatic qualification test not less than six times the design pressure. An exception to this 100,000 cycle requirement is applicable to vessels per RG-404.2 (Filament Winding — Polar Boss Openings Only). That classification of vessels is designed for a 5:1 factor of safety which requires cycling from atmospheric to the design pressure for 33,000 cycles; after this, the test vessel must withstand a hydrostatic qualification test not less than five times the design pressure.

3.3.3 Class II vessels qualified using mandatory design rules and acceptance testing are not required to be subjected to the above cyclic and qualification pressure test criteria.

3.3.4 Section X requires that a Class III design qualification include testing of a prototype vessel that is pressure cycled for "N" cycles as prescribed in 8-700.5.4.1 over a pressure range of 10% of design pressure to 100% of design pressure without leakage or rupture.

3.4 CREEP, STRESS-RUPTURE, AND TEMPERATURE EFFECTS

Fiber-reinforced plastic composite material (laminate) is not subject to creep or failure due to low stress-to-rupture characteristics as are some other materials. The material does, however, lose ultimate strength as the temperature is increased and gains strength but becomes more brittle as the temperature is lowered. Its low thermal conductivity and ablative properties are other factors significantly affecting the behavior of this material in the event of fire or other high-temperature environment. The maximum design, operating, and test temperatures of Class I vessels are set as follows:

(a) 150°F (65°C) for design temperatures less than or equal to 150°F (65°C);

(b) 250°F (120°C) or to within 35°F (19°C) of the glass transition temperature (whichever is lower) for design temperatures in excess of 150°F (65°C).

The maximum design, operating, and test temperatures of Class II vessels are limited to an inside wall temperature of 250°F (120°C) or to within 35°F (19°C) of the glass transition temperature of the resin (whichever is lower). The maximum design temperature of Class III vessels shall be 35°F (19°C) below the maximum use temperature of the resin as documented in the Manufacturing Specifications, but in no case shall it exceed 185°F (85°C). The minimum design temperature of Class I, Class II, and Class III vessels shall be −65°F (−54°C) (see RD-112).

3.5 FABRICATION

3.5.1 Many processes are used in the fabrication of fiber-reinforced composite materials (laminates). Class I vessels are limited to four processes, namely, filament winding, bag molding, contact molding, and centrifugal casting. Class II vessels are limited to two processes, namely, filament winding and contact molding.

3.5.2 The fabrication of more than one Class I vessel may be required to comply with the requirements for qualifying a design using the prototype vessel[3] method. Once a specific design has been qualified, the quality of subsequent vessels of the same dimension and design is to be ensured by carefully controlled fabrication procedures and rigid Quality Control Programs.

3.5.3 Every Class II vessel must be acceptance tested as specified in Article RT-6. Such tests must be documented as having met the acceptance criteria of Article RT-6 and shall become part of the Fabricator's Design Report.

3.5.4 Class III vessels are limited to filament-wound construction with polar loss openings.

3.6 INSPECTION

3.6.1 The general philosophy of Section VIII, Division 1, regarding inspection during fabrication is continued in this Section. Familiarity with the laminate production processes and the nature of vessel imperfections is required of the Inspector. Reliance is placed upon careful auditing of the Fabricator's Quality Control Program, close visual inspection of completed vessels by both Fabricator personnel and the Inspector, and acceptance testing where required by this Section.

3.6.2 This Section requires that all laminate and secondary bonding work be without use of pigments, fillers, or resin putty mixtures except as permitted by the Procedure Specification used in fabricating the vessel or vessel part.

3.7 LINERS

Liners may be used in Section X vessels as a barrier between the laminate and the vessel contents. Such liners shall not be considered part of the structural component of the vessel.

3.8 UNITS

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

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

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

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

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

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

3.8.5 Material that has been manufactured and certified to either the U.S. Customary or SI material specification (e.g., SA-516M) may be used regardless of the unit system used in design. Standard fittings (e.g., flanges, elbows, etc.) that have been certified to either U.S. Customary units or SI units may be used regardless of the units system used in design.

[3] Prototype vessels used to qualify a design shall not be stamped with the Certification Mark.

3.8.6 Conversion of units, using the precision specified in para. 20, shall be performed to ensure that dimensional consistency is maintained. Conversion factors between U.S. Customary units and SI units may be found in the Nonmandatory Appendix, Guidance for the Use of U.S. Customary and SI units in the ASME Boiler and Pressure Vessel Code. Whenever local customary units are used, the Manufacturer shall provide the source of the conversion factors which shall be subject to verification and acceptance by the Authorized Inspector or Certified Individual.

3.8.7 All entries on a Manufacturer's Data Report and data for Code required nameplate marking shall be in units consistent with the fabrication drawings for the component using U.S. Customary, SI, or local customary units. It is acceptable to show alternate units parenthetically. Users of this Code are cautioned that the receiving Jurisdiction should be contacted to ensure the units are acceptable.

SUMMARY OF CHANGES

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

Page	***Location***	***Change***
xiv	List of Sections	Title of Section XI, Division 1 revised
xv	Foreword	Third, fourth, seventh, tenth, and eleventh paragraphs editorially revised
xviii	Personnel	Updated
xliv	Table 1.1	Revised
4	RG-321.1	Subparagraph (a) revised
6	RG-330	Subparagraph (b) revised
8	RM-111	Two paragraphs added after subpara. (e)
8	RM-112	Revised
10	RM-123	Last paragraph revised
27	RD-700	Subparagraph (b) revised
30	RD-900	Second paragraph revised
33	RD-1111	Revised in its entirety
51	RD-1186	Revised
55	RD-1200	Third paragraph revised
55	RD-1210	Second paragraph revised
80	ROP-150	Subparagraphs (f)(1) and (f)(2) revised
104	RS-131	Subparagraph (b) revised
106	RS-301	Subparagraph (c) revised
107	1-110	Subparagraph (c) revised
126	8-300.3	Subparagraph (a) revised in its entirety
127	8-400.1	Third paragraph revised
137	8-700.5.1.1	Revised
137	8-700.5.2.1	Revised
156	10-700	Paragraphs 10-702 through 10-704 and 10-705(c) revised
166	AB-105	Revised
212	Table AJ-1	“Revision” and ”Year” entries for Forms RP-1 through RP-4 revised
224	Form Q-120	On first page, Note and section IC revised
234	Form RP-1	Section 8 revised
237	Form RP-2	Section 8 revised
240	Form RP-3	Section 9 and “Certificate of Design” revised
242	Table AJ-4	Line (26) revised
243	Form RP-4	Section 8 revised

CROSS-REFERENCING IN THE ASME BPVC

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

(a) *Hierarchy of Subparagraph Breakdowns*

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

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

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

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

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

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

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

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

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

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

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

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PART RG
GENERAL REQUIREMENTS

ARTICLE RG-1
SCOPE AND JURISDICTION

RG-100 SCOPE

(a) Section X establishes the requirements for the fabrication of fiber-reinforced thermosetting plastic pressure vessels for general service, sets limitations on the permissible service conditions, and defines the types of vessels to which these rules are not applicable.

(b) To ensure that vessels fabricated according to these rules will be capable of safely withstanding the operating conditions specified by the Design Specification, this Section:

(1) gives minimum requirements for the materials of fabrication;

(2) specifies test procedures for determining laminate mechanical properties;

(3) Defines three methods of design qualification:

(-a) Class I Design — nondestructive qualification test

(-b) Class II Design — mandatory design rules and acceptance testing by nondestructive evaluation (NDE) methods

(-c) Class III Design — qualification of a vessel design through the destructive test of a prototype

(4) suggests nonmandatory design procedures for Class I vessels;

(5) provides mandatory design procedures and acceptance testing for Class II vessels;

(6) defines the general methods of fabrication which may be used;

(7) limits the types of end closures, connections, and attachments which may be employed and the means used to join them to the vessels;

(8) stipulates the procedures to be used in proving that prototype vessels will withstand specified operating and test conditions;

(9) establishes rules under which fabricating procedures used for fabricating Class I and Class III prototype and production vessels are qualified, and defines what deviations from such procedures necessitate requalification;

(10) sets forth requirements to ensure that no essential variation in qualified fabrication procedures has occurred;

(11) establishes rules for acceptance testing, inspection, and reporting;

(12) gives requirements for stamping and marking.

(c) For vessels fabricated in accordance with these rules, the provisions of Section X shall apply over any other sections of the Code. When metallic components are part of fiber-reinforced plastic vessels, they shall meet the provisions of Section VIII, Division 1.

(d) The Fabricator shall establish the effective Code edition, addenda and Code Cases for pressure vessels and replacement parts in accordance with Mandatory Appendix 9.

RG-110 APPLICATION LIMITATIONS

RG-111 DESIGN PRESSURE

The internal design pressure of vessels fabricated under this Section shall be limited as follows:

(a) Class I vessels shall not exceed 150 psi (1 MPa) for bag-molded, centrifugally cast, and contact-molded vessels; 2,000 psi (14 MPa) for filament-wound vessels and 3,000 psi (20 MPa) for filament-wound vessels with polar boss openings only.

(b) Class II vessels shall not exceed the limits specified in RD-1120.

(c) Class III vessels shall not exceed 15,000 psi (103.4 MPa) for filament-wound vessels with polar boss openings only.

RG-112 DESIGN TEMPERATURE

The design temperature of vessels fabricated under this Section shall not exceed the lower of (a) or (b).

(a) 250°F (120°C) for Class I and Class II, and 185°F (85°C) for Class III

(b) 35°F (19°C) below the maximum use temperature (see RM-121) of the resin, nor be less than −65°F (−54°C) (see RD-112)

RG-113 POTABLE WATER — SECTION IV APPLICATIONS ONLY

Vessels fabricated under Section X intended for Section IV use are limited to applications permitted therein. The vessels are limited to internal pressure only with a maximum allowable working pressure of 160 psig [1.1 MPa (gage)]. The maximum allowable temperature used shall be 210°F (99°C). The provisions of this paragraph only apply to vessels that are intended for use under Section IV.

RG-114 LETHAL FLUIDS[1]

Vessels fabricated under this Section shall not be used to store, handle, transport, or process lethal fluids.

RG-120 JURISDICTION OF SECTION X

The jurisdiction of this Section is intended to include only the vessel and integral communicating chambers and to terminate at the points defined in the following subparagraphs (a) and (b).

(a) Where external piping is connected to the vessel, the jurisdiction shall terminate at:

(1) the face of the first flange in bolted flange connections;

(2) the first threaded joint in that type of connection;

(3) the first circumferential adhesive-bonded joint in that type of connection.

(b) Where lugs, skirts, or other supporting structures are joined directly to a vessel, the jurisdiction shall terminate at the first joint or connection beyond the vessel, but shall include the attachment of such supporting structures to the vessel.

RG-121 CLASSES OF VESSELS OUTSIDE THE JURISDICTION OF THIS SECTION

The following classes of fiber-reinforced plastic pressure vessels are exempted from the Scope of this Section; however, any pressure vessel within these classes which meets all applicable requirements of this Section may be stamped with the Certification Mark and RP Designator:

(a) pressure containers which are integral parts of components of rotating or reciprocating mechanical devices, such as pumps, compressors, turbines, generators, engines, and hydraulic or pneumatic cylinders, where the primary design considerations and/or stresses are derived from the functional requirements of the device;

(b) piping systems whose primary function is the transport of fluids from one location to another within a system of which it is an integral part;

(c) piping components, such as pipe, flanges, bolting, gaskets, valves, expansion joints, fittings, and pressure containing parts of other components, such as strainers, and devices which serve such purposes as mixing, separating, snubbing, distributing and metering, or controlling flow, provided that the pressure containing parts of such components are generally recognized as piping components for accessories;

(d) vessels which have any part of the shell, heads, nozzles, fittings, or support laminates heated above the temperature limits of RG-112;

(e) vessels having neither an internal nor an external operating pressure exceeding 15 psi (100 kPa) with no limitation on size;

(f) vessels having an inside diameter, or maximum internal cross-sectional dimension, not exceeding 6 in. (152 mm) with no limitation on the length of vessel or pressure;

(g) pressure vessels for human occupancy.[2]

ARTICLE RG-2
ORGANIZATION

RG-200 ORGANIZATION OF THIS SECTION

RG-201 PARTS

This Section is divided into nine major parts:

(a) Part RG, General Requirements, applying to duties and responsibilities and methods of fabrication;

(b) Part RM, Material Requirements, setting forth rules governing materials applicable to all methods of fabrication;

(c) Part RD, Design Requirements, providing design requirements for all methods of fabrication;

(d) Part RF, Fabrication Requirements, giving rules for permissible methods of fabrication;

(e) Part RQ, Qualification Requirements, used in carrying out the methods of fabrication;

(f) Part ROP, Overpressure Protection, giving rules for protection against overpresure;

(g) Part RT, Rules Governing Testing, establishing the following:

(1) methods for qualifying designs and procedure specifications, for quality control testing, and for production testing;

(2) methods for determining lamina strength and elastic properties for design criteria and acceptance testing of Class II vessels;

(h) Part RI, Inspection Requirements, setting forth minimum inspection requirements;

(i) Part RS, Marking, Stamping, and Reports, setting forth marking, stamping, and reporting requirements.

RG-202 ARTICLES, PARAGRAPHS, AND SUBPARAGRAPHS

(a) The Parts of this Section are divided into Articles. Each Article is given a number and a title, (e.g., Part RG, Article RG-3, Responsibilities and Duties).

(b) Articles are divided into paragraphs, which are a three- or occasionally a four-digit number, the first of which corresponds to the Article number; thus under Article RG-3 we find paragraph RG-310, User's Responsibilities.

(c) Paragraphs are divided into subparagraphs. Major subdivisions of paragraphs are designated by suffixing to the above-mentioned three- or four-digit numbers a decimal point followed by a digit or digits. Where necessary, divisions of subparagraphs are indicated by letters and further subdivisions by numbers in parentheses.

(d) Minor subdivisions of paragraphs are indicated by letters instead of decimals followed by digits.

(e) A reference in one of the paragraphs of this Section to another such paragraph includes all of the applicable rules in the referenced paragraph and its subdivisions, unless otherwise stipulated.

ARTICLE RG-3
RESPONSIBILITIES AND DUTIES

RG-300 RESPONSIBILITIES AND DUTIES

The various parties involved in specifying, fabricating, and inspecting vessels under this Section have definite responsibilities or duties in meeting Code requirements. The responsibilities and duties set forth hereinafter relate only to Code compliance and are not to be construed as involving contractual relationships or legal liabilities.

RG-310 USER'S RESPONSIBILITIES — DESIGN SPECIFICATION

The User, or an agent[3] acting in his behalf, requiring that a vessel be designed, fabricated, tested, and certified to be a vessel complying with this Section, shall provide or cause to be provided for such a vessel information as to operating conditions, including intended use and material compatibility with the contents, in such detail as will provide the basis for design, material selection, fabrication, and inspection in accordance with this Section. This information shall be designated hereinafter as the Design Specification.

RG-320 FABRICATOR'S RESPONSIBILITIES

The structural integrity of a vessel or part thereof, including the capability to contain pressure, and its compliance with the Design Report (see RG-321), are the responsibility of the Fabricator. The Fabricator, completing any vessel to be marked with the Certification Mark with RP Designator, has the responsibility of complying with all the requirements of this Section and, through proper certification, of assuring that any work done by others also complies with all the requirements of this Section.

When such parts are fabricated by an organization other than the Fabricator responsible for the completed vessel, they shall be fabricated by an organization having a valid Certificate of Authorization from ASME and be reported to the Fabricator of the completed vessel on Partial Data Report Form RP-2, which shall be certified by both the parts fabricator and the Inspector.

RG-321 FABRICATOR'S DESIGN REPORT

(25) **RG-321.1 Class I Vessel Designs.** Class I vessel designs shall comply as follows:

(a) As a part of the Fabricator's responsibility for the structural integrity of a Class I vessel, and vessel parts fabricated by others as permitted in (g)(5) and RS-301, and its capability to contain pressure, the Fabricator or the design agent responsible to the Fabricator shall make Design Calculations of the type suggested in Nonmandatory Appendix AA. Such Design Calculations shall constitute only a tentative determination that the design, as shown on the drawings, complies with the requirements of this Section for the design conditions set forth in the Design Specification.

(b) For vessels used for potable water, as described in RG-113 (Section IV application), the Fabricator's Design Report shall indicate suitability for potable water use.

(c) It shall be the Fabricator's responsibility to prove that a vessel will safely withstand the service conditions set forth in the Design Specification. The proof shall consist of subjecting one or more prototype vessels to tests, as required by the rules of this Section (see RT-223), and using the procedures established therein. A report of such tests, designated as the Qualification Test Report, shall be prepared and certified by the Fabricator and the Inspector.

Prototype vessels used to qualify a design shall not be stamped with the Certification Mark.

(d) It shall be the Fabricator's responsibility to prepare and qualify a Procedure Specification that shall specify the materials and the procedure employed to fabricate a prototype vessel or vessels used to verify the capability of such vessel or vessels to safely withstand the test and service conditions set forth in the Design Specification. The Procedure Specification shall provide, as a minimum, all the information concerning the fabricating procedure, recorded on the applicable Form Q-106, Form Q-107, Form Q-108, or Form Q-115.

(e) It shall be the Fabricator's responsibility to conduct Quality Control Tests in accordance with the requirements of Article RT-3 and to record the results thereof to permit verification that all other vessels, fabricated in accordance with the qualified Procedure Specification, comply with this Section.

(f) It shall be the Fabricator's responsibility to conduct Production Tests as stipulated in Article RT-4 and to record the results to permit verification that such vessels are in compliance with this Section and are acceptable for marking with the Certification Mark.

(g) It shall be the responsibility of the Fabricator to prepare a Fabricator's Design Report consisting of the following documents:

(1) the Design Specification setting forth the service conditions;

(2) the Design Drawings;

(3) the tentative Design Calculations;

(4) the material manufacturer's specification sheets for resin, fiber reinforcement, promoters, catalyst, and other components used in laminate construction;

(5) a properly certified Form RP-2 for parts of the vessel fabricated by other Fabricators;

(6) the Procedure Specification, providing the fabrication procedures used to fabricate both the prototype vessel(s) and all production vessels to be certified as complying with this Section;

(7) the Qualification Test Report, which provides data that the prototype vessel(s) conforming to the Design Drawings will safely withstand the specified test conditions;

(8) the records of the Quality Control Tests Report, providing the results of the in-process tests used to ensure that no essential variations from the requirements of the Procedure Specification occurred;

(9) the Production Test Report of inspections, examinations, and tests performed on each vessel to be marked with the Certification Mark.

The preceding nine documents shall constitute the Fabricator's Design Report. It shall be certified by the Fabricator. It shall be kept on file at the Fabricator's place of business or at a safe depository acceptable to the User and shall be made available to the Inspector for at least 5 yr. When fabrication of specific mass-produced vessels occurs over an indefinite period of time, the Fabricator's Design Report on each specific design shall be kept on file for at least 5 yr after production of such vessels has ceased. Copies of the Design Drawings and Design Calculations shall be furnished to the User or his agent and, when requested, a copy of the Test Report shall also be furnished.

RG-321.2 Class II Vessel Designs. Class II vessel designs shall comply as follows:

(a) As part of the Fabricator's responsibility for the structural integrity of the vessel, and vessel parts fabricated by others as permitted in (e)(5) and RS-301, and its ability to contain pressure, the Fabricator of the vessel shall be responsible for Design Calculations as specified in Article RD-11. Such calculations shall constitute the basis for thickness of parts subject to pressure, number of plies, ply orientation, and other fabrication details specified on drawings and other fabrication documents. Such calculations shall be part of the Design Report.

(b) It shall be the Fabricator's responsibility to document the elastic and strength constants of the laminate or laminates used for Design Calculations. The lamina or laminas used for vessel laminate construction shall be the same as the lamina or laminas from which elastic and strength constants were determined and which served as a basis for Design Calculations and laminate analysis. The number of laminas, stacking sequence, and orientation of each lamina shall be the same as used on the laminate analysis for design purposes. Determination of laminate stiffness coefficients shall be in accordance with Article RD-12. The determination of lamina elastic and strength properties shall be in accordance with Article RT-7. As an alternative, the lamina elastic properties may be determined in accordance with Nonmandatory Appendix AK. A report of such test, designated as the Material Property Test Report, shall be part of the Fabricator's Design Report and shall be made available to the Inspector.

(c) It shall be the Fabricator's responsibility to prepare and certify a Procedure Specification that shall specify the materials and fabrication procedures used to fabricate the specified vessel. The Procedure Specification shall provide, as a minimum, all the information required by Form Q-120, which shall verify that the vessel was fabricated according to that specification.

(d) It shall be the Fabricator's responsibility to subject each vessel fabricated under this method to acceptance testing as specified in Article RT-6. A report of such test, designated as the Acceptance Test Report, shall be part of the Fabricator's Design Report and shall be made available to the Inspector.

(e) It shall be the Fabricator's responsibility to prepare and certify a Fabricator's Design Report consisting of the following documents:

(1) the Design Specification setting forth the design conditions;

(2) the Design Drawings including Procedure Specification number;

(3) the Design Calculations;

(4) the material manufacturer's specification sheets for all materials used in lamina testing and laminate fabrication;

(5) a properly certified Form RP-4 for vessel parts fabricated by other Fabricators;

(6) the Procedure Specification to which the vessel was fabricated;

(7) the Acceptance Test results including the acoustic emission report, to be designated as the Acceptance Test Report;

(8) the documentation of the elastic and strength properties of the lamina(s) as specified and determined in Article RT-7 or Nonmandatory Appendix AK, as applicable, to be designated as the Material Property Test Report.

The preceding eight documents shall constitute the Fabricator's Design Report. It shall be certified by the Fabricator. It shall be kept on file at the Fabricator's place of business or at a safe depository acceptable to the User and shall be made available to the Inspector for at least 10 yr. A copy of the Design Report shall be furnished to the User or his agent.

RG-322 CERTIFICATION OF COMPLIANCE

It is the responsibility of the Fabricator to certify compliance with the rules of this Section by execution of the appropriate Fabricator's Data Report (see Forms RP-1, RP-2, RP-3, and RP-4). (The vessel may be registered and the Data Report filed with the National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, Ohio 43229.) See Article RS-3.

RG-323 REQUIREMENTS FOR QUALITY CONTROL

Any Fabricator applying for an official Certification Mark with RP Designator of The American Society of Mechanical Engineers and the Certificate of Authorization shall have, and demonstrate, a Quality Control System which ensures that all Code requirements, including material, design, fabrication, examination by the Fabricator, and inspection by the Inspector, will be met. The Quality Control System shall be in accordance with the requirements of Mandatory Appendix 1.

Before issuance or renewal of a Certificate of Authorization for use of the Certification Mark with RP Designator, the Fabricator's facilities and organization are subject to a joint review by a representative of his inspection agency and an individual certified as an ASME designee who is selected by the concerned legal jurisdiction. A written description or checklist of the Quality Control System which explains what documents and what procedures the Fabricator will use to fabricate a Code item shall be available for review. A written report to the Society shall be made jointly by the ASME designee and the inspection agency under contract to the Fabricator to provide inspection services provided by this Section.

The Fabricator may at any time make changes to the Quality Control System concerning the methods of achieving results, subject to acceptance by the Inspector.

The Fabricator shall have in force at all times a valid inspection contract or agreement with an agency employing Inspectors as defined in RI-110. A valid inspection contract or agreement is a written agreement between the Fabricator and the inspection agency in which the terms and conditions of furnishing the inspection service are specified and in which the mutual duties of the Fabricator and the Inspector are stated.

For those areas where there is no jurisdiction or where a jurisdiction does not choose to select an ASME designee to review a vessel or vessel parts Manufacturer's facility, that function shall be performed by an ASME designee selected by ASME.

Where the jurisdiction is the Fabricator's inspection agency, the joint review and joint report shall be made by the jurisdiction and another representative designated by an ASME designee.

RG-330 INSPECTOR'S DUTIES (25)

(a) It is the duty of the Inspector to make the inspections required by the rules of this Section and, in addition, such other inspections and investigations as are necessary in his judgment to verify that:

(1) the User's Design Specification is available;

(2) the Fabricator's Design Report is on file and has been properly executed;

(3) the fabrication conforms to the Design Drawings;

(4) the material and fabrication procedures being used comply with the requirements of the specified Procedure Specification;

(5) the tests stipulated in Part RT substantiate that the Procedure Specification(s) was followed.

(b) It is not the duty of the Inspector to verify the accuracy or completeness of the Design Calculations, but the Inspector shall verify that the completed Design Report is on file. The Inspector shall certify compliance with the Procedure Specification used for qualifying the design and fabrication of the vessel.

(c) The Inspector shall certify on the Fabricator's Data Report that the requirements of this Section have been met.

ARTICLE RG-4
FABRICATION METHODS

RG-400 FABRICATION METHODS[4]

For purposes of this Section, fiber-reinforced plastic pressure vessels are divided into four methods of fabrication. Class I vessels may be fabricated by any combination of these methods. Class II vessels are restricted to the contact-molding and filament-wound methods of fabrication or a combination of the two.

RG-401 BAG MOLDING5[5]

In this method a pressurized bag is used to compress pre-rolled fiber cylinders and head preforms, which are impregnated with the specified resin system, against an outer heated mold.

RG-402 CENTRIFUGAL CASTING

In this method the sections of the vessel are formed from chopped fiber strands and a resin system in a mandrel, which is spun to produce a laminate, and heated to effect a cure of the resin system.

RG-403 CONTACT MOLDING

In this method cylindrical sections, heads, and/or attachments are fabricated by applying reinforcement fiber and resin to a mandrel or mold. System cure is either at room temperature or elevated temperature using a catalyst–promoter system.

RG-404 FILAMENT WINDING

RG-404.1 General. In this method, continuous filaments of fiber with the specified resin applied are wound in a systematic manner under controlled tension and cured on a mandrel or other supporting structure. Heads and fittings fabricated by contact-molding methods may be attached with suitable adhesive resins and secondary reinforcement with cutting of filaments as required. Opening(s) may be integral wound or with cutting of filaments as required and need not be centered on the axis of rotation.

RG-404.2 Polar Boss Openings Only. In this special case which qualifies for reduced cycle and burst test requirements per RT-223.5, heads shall be integrally wound and satisfy the following criteria:

(a) opening(s) shall be centered on the axis of rotation;

(b) opening(s) shall be a polar boss type, wound in place at the center of revolution;

(c) boss diameter shall not exceed one-half vessel I.D.;

(d) no cutting of filaments is permitted to form the polar boss opening.

PART RM MATERIAL REQUIREMENTS

ARTICLE RM-1 GENERAL REQUIREMENTS

RM-100 LAMINATE MATERIALS

Fiber-reinforced plastic materials shall hereinafter be designated as laminates.

(a) Laminates, as herein considered, are composite structures consisting of one or more of the following reinforcements embedded in a resin matrix:

(1) glass
(2) carbon or graphite
(3) aramid

(b) The Fabricator shall keep on file the published specifications for all laminate materials used in each vessel fabrication, the material manufacturer's recommendations for storage conditions and shelf life for all laminate materials, and the material manufacturer's certification that each shipment conforms to said specification requirements. This certification shall be part of the Procedure Specification.

RM-110 FIBER SYSTEM

(25) **RM-111 GLASS FIBERS**

The glass fibers used in any of the fabrication processes permitted by this Section shall be one or more of the following glass compositions:

(a) Type A
(b) Type E
(c) Type S
(d) Type E-CR
(e) Type C

Type S and Type E-CR glass compositions are recommended due to their corrosion resistance.

Type A, Type E, and Type C glass compositions include boron, which makes them sensitive to attack by acids. This sensitivity to acid attack shall be considered in vessel design and use. These glass compositions may be used for nonstructural purposes, such as veil mat.

The glass manufacturer shall certify that the fibers conform to the manufacturer's specifications for the product and that the minimum strength and modulus, measured in accordance with ASTM D2343, are not less than 90% of the manufacturer's published minimum values for resin-impregnated strands.

RM-112 CARBON OR GRAPHITE FIBERS (25)

The fiber manufacturer shall certify that the carbon or graphite fibers conform to the manufacturer's specifications for the product and that the minimum strength and modulus, measured in accordance with ASTM D4018, are not less than 90% of the manufacturer's published minimum values for resin-impregnated strands.

RM-113 ARAMID FIBERS

The fiber manufacturer shall certify that the aramid fibers conform to the manufacturer's specifications for the product and that the minimum strength and modulus, measured in accordance with ASTM D2343, are not less than 90% of the manufacturer's published minimum values for resin-impregnated strands.

RM-114 FIBER SURFACE TREATMENT

The surface of glass, carbon, and graphite fiber shall be treated to provide a bond between the fiber and resin matrix. Aramid fibers do not normally require surface treatment.

RM-120 RESIN SYSTEM

The resin system shall consist of an epoxy or polyester/vinyl ester, phenolic, or furan resin plus the resin manufacturer's recommended promoters and curing agents. No filler, pigment, thixotrope, or dye which will interfere with the natural color of the resin shall be used except as permitted by the Procedure Specification. If required by the User, the vessel may be painted following all required inspections and certifications by the Inspector.

RM-121 RESIN SPECIFICATION

The resin materials used in the fabrication of vessels shall be the same as those specified in the Procedure Specification. Each resin shall be traceable by the name of its manufacturer and the trade name or number of that manufacturer.

The resin manufacturer shall supply to the Fabricator a Certificate of Analysis for each resin used. It shall include the following information:

(a) resin identification
(b) batch number(s)
(c) date of manufacture

In addition, the resin manufacturer shall certify for each batch shipped, the value (and the limits stipulated in his specification) of the properties identified in Table RM-120.1.

The Fabricator shall test each batch of resin in accordance with Table RM-120.2 for the appropriate resin to ensure that the material characteristics of the resin have not changed from specified values listed in the Procedure Specification.

The values obtained for viscosity and specific gravity for the resin alone shall be within the limits of the manufacturer's specification for that resin and as listed in the Procedure Specification. The resin testing shall be done at first usage.

The values obtained for gel-time and peak-exotherm temperature shall be for a particular resin/curing system test formulation and temperature, and shall be within the limits listed in the Procedure Specification. The test formulation and temperature shall be representative of the formulations used during vessel fabrication. The tolerance limits for the test formulation (as listed in the Procedure Specification) may be established by either the resin manufacturer or the Fabricator. The tolerance limits shall be established using formulation components having manufacturer-specified material characteristics. The tolerance limits established shall be within a sufficiently narrow range such that test results outside this range would reflect deviations in component material characteristics and alert the Fabricator of possible material irregularities. Material tested and found to be inside the established tolerance limit range shall be deemed fit for use.

In addition, the Fabricator shall establish and document a maximum use temperature for the resin/cure system used. This may be in conjunction with the resin manufacturer or independent laboratory, and may be based on heat distortion temperature or glass transition temperature. The Fabricator shall redocument the maximum use temperature at least every twelve months using current batches of resin and curing agent.

A record of these determinations shall become part of the Fabricator's Quality Control Tests Report and shall be made available to the Inspector.

The data for each batch of resin which is used to fabricate a Class II vessel shall be recorded on the Procedure Specification (see Form Q-120) and become part of the Fabricator's Design Report for that vessel.

Table RM-120.1
Resin Systems Required Certification by Resin Manufacturer

Resin System	Required Certification [Note (1)]
Polyester/Vinyl Ester	
1. Viscosity	ASTM D445 or ASTM D2393
2. Specific gravity	Wt. per gallon cup or ASTM D4052
Epoxy	
1. Viscosity	ASTM D445 or ASTM D2393
2. Epoxide equivalent	ASTM D1652
3. Specific gravity	Wt. per gallon cup or ASTM D4052
Furan/Phenolic	
1. Viscosity	ASTM D445 or ASTM D2393
2. pH	Glass electrode method
3. Total volatiles	Similar to ASTM D3030
4. Specific gravity	Wt. per gallon cup or ASTM D4052

NOTE: (1) Alternate documented method may be used.

Table RM-120.2
Resin Systems Required Test by Vessel Fabricator

Resin System	Required Test [Note (1)]
Polyester/Vinyl Ester	
1. Viscosity	ASTM D445 or ASTM D2393
2. Gel time and peak exotherm temperature	ASTM D2471
3. Specific gravity	Mandatory Appendix 5 or ASTM D4052
Epoxy	
1. Viscosity	ASTM D445 or ASTM D2393
2. Gel time	ASTM D2471
3. Specific gravity	Mandatory Appendix 5 or ASTM D4052
Furan/Phenolic	
1. Viscosity	ASTM D445 or ASTM D2393
2. Gel time	Not Applicable
3. Specific gravity	Mandatory Appendix 5 or ASTM D4052

NOTE: (1) Alternate documented method may be used.

RM-122 CURING AGENTS

The curing agents used, and curing procedure followed, in the vessel fabrication shall be as specified in the Procedure Specification. Each such curing agent shall be traceable by the manufacturer's name, the manufacturer's designation, and the generic name.

The curing agent and the resin-to-curing-agent ratio used to fabricate vessels shall be recorded and become part of the Quality Control Tests Report specification.

(25) RM-123 LAMINATE CURE

The Fabricator shall determine and document as part of the Procedure Specification and the Quality Control Tests Report that the laminate of each vessel and vessel part is properly cured.

This shall normally be done using the Barcol Test in accordance with ASTM D2583 (see RQ-141 and RT-221). Barcol readings shall be within the tolerance specified by the resin manufacturer as listed in the Procedure Specification. If the resin manufacturer does not provide Barcol specifications (for the resin/curing system used), the Fabricator shall establish Barcol specifications (for the resin/curing system used) that have been documented by independent third party testing that such Barcol readings are indicative of complete resin cure. These shall become part of the Procedure Specification.

If the Fabricator elects not to use the Barcol Test as a measure of proper laminate cure, the Fabricator shall define and document the method used to ensure that proper laminate cure is attained. Such method(s) shall be acceptable to the Inspector. The results thereof shall be part of the Procedure Specification and Quality Control Tests Report recorded in lieu of Barcol Test results on the various forms.

RM-140 USE OF TWO OR MORE MATERIALS SPECIFICATIONS OR PROCESSES IN FABRICATING A CLASS I VESSEL

Two or more Procedure Specifications may be used in fabricating a pressure vessel, provided each Procedure Specification is used in its entirety for the part of the vessel fabricated with that procedure.

RM-150 MECHANICAL PROPERTIES OF LAMINA FOR CLASS II VESSELS

RM-151 EXAMPLES OF LAMINA

For the purposes of this Section, a lamina is defined as a layer or multiple layers of the same material and same orientation. An example of a lamina is a layer of thermoset resin reinforced with chopped strand mat, unidirectional reinforcement, or woven roving.

As a single exception and in the absence of thermal stress, due to existing fabrication methods, alternate layers of chopped strand mat and woven roving may be considered as a lamina.

RM-152 LAMINA SPECIFICATION

The lamina, lamina stacking sequence, and orientation shall be specified in the Procedure Specification.

RM-153 LAMINA PROPERTIES

The lamina strength properties shall be determined in accordance with Article RT-7. The lamina elastic properties shall be determined in accordance with either Article RT-7 or Nonmandatory Appendix AK.

RM-154 LAMINATE ANALYSIS

The lamina properties shall be used to analyze the laminate and determine effective laminate elastic constants in accordance with Article RD-12.

ARTICLE RM-2
MISCELLANEOUS PRESSURE PARTS

RM-200 GENERAL REQUIREMENTS

All portions of the vessel which are under the jurisdiction of this Section and which are fabricated of laminate materials by the Fabricator responsible for the completed vessel, or by other parties, shall conform to all applicable requirements of this Section, including inspection in the shop of the Fabricator. In addition, parts fabricated by parties other than the Fabricator responsible for the completed vessel shall require inspection in the shop of the part fabricator and preparation of a Partial Data Report, Forms RP-2 and RP-4, as applicable.

RM-210 MISCELLANEOUS METALLIC PARTS

RM-211 FOR CLASS I VESSELS

Metallic parts for Class I vessels shall comply with the design, fabrication, quality control, and inspection requirements of Section VIII, Division 1. For hydrostatic leakage testing, metallic parts shall comply with the requirements of RT-450.

RM-212 FOR CLASS II VESSELS

The only metallic parts permitted for Class II vessels shall be removable parts such as multibolted flat flange covers and fasteners. Such parts shall comply with all requirements of Section VIII, Division 1.

PART RD
DESIGN REQUIREMENTS

ARTICLE RD-1
GENERAL

RD-100 SCOPE

Section X provides two methods by which the thickness of vessel parts subject to internal or external pressure may be determined:

(a) Class I Design — qualification and testing of a prototype vessel;

(b) Class II Design — mandatory design rules and acceptance testing.

For Class I vessels, tentative thickness of vessel parts may be determined by the suggested design procedures given in Nonmandatory Appendix AA or by other procedures at the Fabricator's option. Regardless of how the thicknesses of vessel parts are determined, the adequacy of the design of a vessel or vessels to be certified for specified service conditions shall be determined by testing one or more prototype vessels in accordance with the requirements of Article RT-2; all vessels to be so certified shall be constructed in strict accordance with the Procedure Specification used in fabricating the prototype vessel or vessels (see Article RQ-1).

For Class II vessels, thickness of vessel parts and other fabrication details shall be determined by procedures specified in Article RD-11. The number of plies and ply orientation shall be as specified in the Procedure Specification, Form Q-120.

RD-101 DESIGN BASIS

(a) The pressure of the fluid at the top of the vessel in its normal operating position, with the laminate temperature for Class I vessels taken at 150°F (65°C) for design temperatures less than or equal to 150°F (65°C) or at the specified design temperature when the design temperature exceeds 150°F (65°C), shall be that on which the design is based. The pressure of the fluid at the top of the vessel in its normal operating position with the laminate temperature as specified in the Design Specification for Class II vessels, shall be that on which the design is based. When applicable, static head shall be included in establishing the design basis. The pressure at the top of the vessel is also the basis for the pressure setting of the pressure relief devices protecting the vessel.

(b) The design shall take into account the maximum difference in fluid pressure which can occur under the conditions of operation specified in the Design Specification (which may include pressure due to static head) between the inside and outside of the vessel at any point or between two chambers of a combination unit.

(c) The design shall take into account all combinations of loadings other than pressure (see RD-120) which may occur, coincident with the specified operating pressure and temperature. For Class I vessels, any additional thickness required to withstand such supplementary loadings shall be added to that required to withstand pressure loading as determined by the requirements of Article RT-2. For Class II vessels, such supplementary loadings shall be included in the Design Calculations.

(d) When liners, whether metallic or nonmetallic, are installed in vessels covered by this Section, no credit shall be given to the strength of the liner in establishing the design pressure. However, the weight of the liner shall be taken into account when determining loadings other than pressure.

Applications that require a liner for corrosion resistance purposes shall be so identified in the Design Specification. Any part of the laminate, such as an inner surface and interior layer composition as described in ASTM D4097, that is intended for corrosion resistance shall be so designated in the Procedure Specification. The thickness of this part of the laminate shall be in addition to that required for pressure and other loading considerations.

RD-110 DEFINITIONS

The terms relating to design used throughout this Section, together with limiting values, are defined in RD-111 through RD-116.