Packers and Bridge Plugs

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Introduction

This specification has been developed by users/purchasers and suppliers/manufacturers of packers and bridge plugs and is intended for use in the petroleum and natural gas industry worldwide to give requirements and information to both parties in the selection, manufacture, testing, and use. Further, this specification addresses the minimum requirements to which the supplier/manufacturer is to conform.

This specification has been structured with grades of increased requirements in design validation and levels in quality control. These grades/levels allow the user/purchaser to select the grade/level required for a specific application.

There are three quality levels: Quality level QL3 is the minimum level of quality offered by this product standard. Quality level QL2 provides additional inspection and verification steps. Quality level QL1 is the highest level provided. Additional quality requirements may be specified by the user/purchaser as supplemental requirements.

There are 16 design validation grades to provide the user/purchaser the choice of requirements to meet a specific preference or application. Design validation grades V0-HR to V6-R are new 4th edition grades, and design validation grades V0 to V6 are for legacy products with design verification and validation requirements listed in Annex A. Design validation grade V6 is the minimum grade and represents equipment where the validation method has been defined by the supplier/manufacturer. V0-HR and V3-HR are for high pressure high temperature (HPHT) applications with specific requirements listed in Annex B and have replaced the legacy V0-H and V3-H validation grades. The complexity and severity of the validation testing increases as the grade number decreases.

This edition has been completely revised. Changes include moving requirements from the HPHT annex (Annex B) into the main body, consolidating common validation requirements, and organizing the validation tests into tables. New requirements for low temperature ratings validation and test report requirements have been added.

This edition now includes a new normative annex for legacy product requirements (Annex A) and three new informative annexes: optional requirements for validation of hydrostatically set products (Annex E), determining text fixture inside diameter (Annex F), and tubing-to-packer forces and rated performance envelopes (Annex G). Annex B has also been changed from informative to normative.

The International System of Units (SI) is used in this specification; however, US Customary (USC) or other units are also shown for reference.

It is necessary that users of this specification be aware that requirements beyond those outlined in this specification can be needed for individual applications. This specification is not intended to inhibit a supplier/manufacturer from offering, or the user/purchaser from accepting, alternative equipment or engineering solutions. This can be particularly applicable where there is innovative or developing technology.

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Packers and Bridge Plugs

1 Scope

This specification provides requirements and guidelines for packers and bridge plugs as defined herein for use in the petroleum and natural gas industry. This specification provides requirements for the functional specification and technical specification, including design, design verification and validation, materials, documentation and data control, repair, shipment, and storage.

Products covered by this specification apply only to applications within casing or tubing. Products covered by other API specifications, such as API 19OH or API 19LH, are not covered by this specification. Installation and maintenance of these products are outside the scope of this specification.

Within this specification the term product is used to indicate both packers and bridge plugs.

This specification includes the following annexes:

— Annex A: Requirements for Legacy Products

— Annex B: Requirements for HPHT Environment Equipment;

— Annex C: Requirements for HPHT Operational Tools;

— Annex D: Requirements for External Flow Testing;

— Annex E: Validation of Maximum Initiation Pressure for Hydrostatically Set Products;

— Annex F: Determining Test Fixture Inside Diameter;

— Annex G: Tubing-to-Packer Forces and Rated Performance Envelopes.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Specification 20A, *Carbon Steel, Alloy Steel, Stainless Steel, and Nickel Base Alloy Castings for Use in the Petroleum and Natural Gas Industry,* 1st Edition

API Specification Q1, *Specification for Quality Management System Requirements for Manufacturing Organizations for the Petroleum and Natural Gas Industry*

ANSI [1]/NACE MR0175 [2]/ISO 15156 [3], *Petroleum and natural gas industries—Materials for use in H2S-containing environments in oil and gas production*

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[1] American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, New York 10036, www.ansi.org.

[2] NACE International, 15835 Park Ten Place, Houston, Texas 77084, www.nace.org.

[3] International Organization for Standardization, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, www.iso.org.

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ASME *Boiler and Pressure Vessel Code (BPVC)* [4], *Section VIII, Division 1: Rules for Construction of Pressure Vessels*, 2019 Edition

ASME *BPVC*, *Section VIII, Division 2: Alternative Rules*, 2019 Edition

ASME *BPVC*, *Section VIII, Division 3: Alternative Rules for Construction of High Pressure Vessels*, 2019 Edition

ASME *BPVC, Section V: Nondestructive Examination*

ASME *BPVC, Section IX: Welding and Brazing Qualifications*

ASNT SNT-TC-1A [5], *Personnel Qualification and Certification in Nondestructive Testing*

ASTM A388/A388M [6], *Standard Practice for Ultrasonic Examination of Steel Forgings*

ASTM D297, *Standard Test Methods for Rubber Products—Chemical Analysis*

ASTM D395, *Standard Test Methods for Rubber Property—Compression Set*

ASTM D412, *Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension*

ASTM D429, *Standard Test Methods for Rubber Property—Adhesion to Rigid Substrates*

ASTM D638, *Standard Test Method for Tensile Properties of Plastics*

ASTM D790, *Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials*

ASTM D1414, *Standard Test Methods for Rubber O-Rings*

ASTM D1415, *Standard Test Method for Rubber Property—International Hardness*

ASTM D1708, *Standard Test Method for Tensile Properties of Plastics by Use of Microtensile Specimens*

ASTM D2240, *Standard Test Method for Rubber Property—Durometer Hardness*

ASTM D2990, *Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics*

ASTM E21, *Standard Test Methods for Elevated Temperature Tension Tests of Metallic Materials*

ASTM E94/E94M, *Standard Guide for Radiographic Examination Using Industrial Radiographic Film*

ASTM E127, *Standard Practice for Fabrication and Control of Flat Bottomed Hole Ultrasonic Standard Reference Blocks*

ASTM E165/E165M, *Standard Practice for Liquid Penetrant Testing for General Industry*

ASTM E709, *Standard Guide for Magnetic Particle Testing*

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[4] American Society of Mechanical Engineers, Two Park Avenue, New York, New York 10016, www.asme.org.

[5] American Society for Nondestructive Testing, 1711 Arlingate Lane, Columbus, Ohio 43228, www.asnt.org.

[6] ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

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ISO 2859-1, *Sampling procedures for inspection by attributes—Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection*

ISO 3601-1, *Fluid power systems—O-rings—Part 1: Inside diameters, cross-sections, tolerances and designation codes*

ISO 3601-3, *Fluid power systems—O-rings—Part 3: Quality acceptance criteria*

ISO 9712, *Non-destructive testing—Qualification and certification of NDT personnel*

ISO 10893-4:2011, *Non-destructive testing of steel tubes—Part 4: Liquid penetrant inspection of seamless and welded steel tubes for the detection of surface imperfections*

ISO 10893-5:2011, *Non-destructive testing of steel tubes—Part 5: Magnetic particle inspection of seamless and welded ferromagnetic steel tubes for the detection of surface imperfections*

ISO 23936-2:2011, *Petroleum, petrochemical and natural gas industries—Non-metallic materials in contact with media related to oil and gas production—Part 2: Elastomers*

3 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

3.1
assembly
Product comprised of more than one component.

3.2
bridge plug
Mechanical device, with packing element, used for blocking fluid (liquid or gas) communication in a section of casing or tubing.

3.3
casing
Pipe run from the surface and intended to line the walls of a drilled well.

NOTE Casing that does not extend to the surface is a liner.

3.4
casing size
tubing size
Nominal casing or tubing outside diameter (OD).

3.5
component
Individual part of an assembly.

3.6
design margin
Ratio of the material minimum yield stress divided by the actual design stress in a component at the rated conditions.

3.7
design validation
Process of proving a design by testing to demonstrate conformity of the product to design requirements.

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3.8
design verification
Process of examining the result of a given design or development activity to determine conformity with specified requirements.

3.9
drift diameter
Inside diameter (ID) of the product, expressed as the OD of the drift bar used during assembly inspection.

3.10
end connection
Thread or other mechanism connecting the product to the casing or tubing.

3.11
exposed component
Flow-wetted component, internally wetted component, and/or component contacted by well fluid below the packing element.

3.12
flow-wetted component
Component that comes in direct contact with the movement of well fluids in the flow stream.

3.13
internally wetted component
Flow-wetted component and any component out of the flow stream, but contacted by well fluids through a port or other passage to the flow-wetted area.

3.14
job-lot
Batch of material or components that have undergone the same process or series of processes.

3.15
legacy product
Existing product that has been validated to the requirements of a previous edition of API Spec 11D1.

3.16
mandrel
Component(s) that contain(s) the end connections and provide(s) a conduit through the packer.

3.17
manufacturing
Process and actions performed by an equipment supplier/manufacturer that are necessary to provide finished component(s), assemblies, and related documentation that fulfil the requests of the user/purchaser and meet the standards of the supplier/manufacturer.

3.18
NACE service
Service for products whose type 1 components are manufactured from metallic materials that conform to material and service requirements of the applicable section(s) of ANSI/NACE MR0175/ISO 15156.

3.19
packer
Mechanical device with a packing element, used for blocking fluid (liquid or gas) communication through the annular space between casing and tubing by sealing off the space between them.

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3.20
packing element
Seal on the product that blocks fluid communication by sealing on the ID of the casing or tubing.

3.21
performance envelope
Graph that illustrates the combined effects of differential pressure and axial loads on a product at the rated temperature.

3.22
permanent packer
permanent bridge plug
Bridge plug or packer that has no design feature for intact retrieval or repositioning.

3.23
pressure reversal
Change in the direction of the pressure differential across the packing element from above to below or vice versa.

3.24
product family
A group of assemblies where the design principles for the geometry, materials, and functionality are the same.

3.25
qualified person
Individual with characteristics or abilities gained through training or experience, or both, as measured against established requirements, such as standards or tests that enable the individual to perform a required function effectively.

3.26
repositionable packer
repositionable bridge plug
Bridge plug or packer that meets the definition of retrievable packer (retrievable bridge plug) and has a design feature facilitating its relocation (without retrieval) followed by re-establishing its intended function.

3.27
retrievable packer
retrievable bridge plug
Bridge plug or packer that has a design feature facilitating its retrieval.

3.28
seal
Device providing a barrier to the passage of liquid and/or gas.

3.29
seal diameter
The supplier/manufacturer-defined diameter used to calculate hydraulically induced loads on the product.

NOTE Annex G provides information on the use of seal diameters in calculations.

3.30
shear device
Component designed to disconnect under a predetermined load.

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3.31
standard service
Service for products whose components are not required to conform to material and service requirements of the applicable section(s) of ANSI/NACE MR0175/ISO 15156.

3.32
substantive design change
Change to the design, identified by the supplier/manufacturer, that affects the performance of the product in the intended service condition.

3.33
temperature-cycle range
Specified amount of temperature change within the product's temperature range over which the product is designed to operate.

NOTE The temperature-cycle range is validated for V3-R, V3, V1-R, V1, V0-R, V0, V0-HR, and V3-HR, and is applicable anywhere within the product's temperature range (see 6.3.4.3).

3.34
temperature range
Specified range of minimum and maximum temperatures over which the product is designed to operate.

3.35
tubing
Pipe placed in a well to produce or inject fluids.

3.36
type 1 component
type 1 weld
Metallic component or weld that isolates pressure and/or is loaded in tension as the result of axial loads on the product during run-in, setting, service, or retrieval.

3.37
type 2 component
type 2 weld
Metallic component or weld that does not meet the criteria of a type 1 component or weld.

4 Acronyms, Abbreviations, and Symbols

AQL acceptance quality limit

COC certificate of compliance

FEA finite element analysis

FMEA failure modes and effects analysis

HPHT high pressure high temperature

ID inside diameter

L length

MTR material test report

NDE nondestructive examination

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OD outside diameter

RGD rapid gas decompression

t thickness

ρ density

5 Functional Specification

5.1 General

The user/purchaser shall prepare a functional specification for ordering products that conform to this specification and specify the following requirements and operating conditions, as applicable, and/or identify the supplier's/manufacturer's specific product. These requirements and operating conditions may be conveyed by means of a dimensional drawing, data sheet, or other suitable documentation. If not provided, the supplier/manufacturer shall generate a functional specification.

NOTE The supplier/manufacturer can generate internal requirements for products as the user/purchaser.

5.2 Type Description

The functional specification shall specify the following type:

— permanent packer or bridge plug, or

— retrievable packer or bridge plug, or

— repositionable packer or bridge plug.

5.3 Well Parameters

The functional specification shall specify, as applicable, the following well parameters:

— dimensions, material, grade of the casing and/or tubing;

— end connections above/below the product;

— well angle from the vertical at the setting position of the product;

— deviations, dog-leg severity, and restrictions through which the product is required to pass;

— size, type, and configuration of other products and tubulars used in connection with this product;

— other lines (electrical/hydraulic) that are required to pass through or bypass the packer;

— internal receptacle profile(s), bore dimensions(s), outside diameter (OD), inside diameter (ID), and the respective locations;

— expected minimum and maximum values of production/injection pressures, pressure differentials, temperatures, changes in temperatures, and flow rates;

— any other relevant well parameter(s).

NOTE 1 A well schematic can be useful to identify many well parameters and related well equipment.

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NOTE 2 Annex G includes information on sealing diameter and pressure-induced loads.

5.4 Operational Parameters

The functional specification shall specify, as applicable, any of the following operational parameters:

— installation method, including conveyance method, such as tubing, wireline, tractor, or coil tubing;

— setting method and allowable pressures during setting;

— anticipated running/pulling speed(s);

— setting depth;

— retrieving or repositioning method and number of repositionings, if applicable;

— anticipated loading conditions, applied to the product prior to and during setting, during use, and during retrieving, including combined loading (pressure, tension/compression, torque) and loading due to perforating events;

— expected setting temperature and anticipated temperature cycle during well operations;

— size, type, and configuration of devices, service tools, or well servicing activities that will interface with or run through the product;

— flow rates, exposure time, and composition of fluids flowing across or exposed to the packing element;

— well stimulation operations, including its parameters, such as acidizing (composition of the acid and acid returns), the pressure, the temperature, the acid flow rate and the exposure time, and other chemicals used during the stimulation;

— well cementing operations, including its parameters, such as cement types and volumes, spacers, plugs, pressure, flow rates, and top of cement;

— sand consolidation and fracturing operations, including sand/proppant description and volume, fluid flow rate, proppant/fluid ratio or sand/fluid ratio, chemical composition, pressure, and temperature;

— intended removal and/or milling operations;

— service life;

— any other relevant operational parameters.

NOTE Annex D provides information on external flow testing.

5.5 Environmental Compatibility

5.5.1 General

If the user/purchaser has access to the corrosion property data of the operating environment based on historical data and/or research, the user/purchaser shall state to the supplier/manufacturer which material(s), metals or nonmetals, has/have the ability to perform as required. If the user/purchaser does not provide the material selection to the supplier/manufacturer, the material compatibility shall be determined according to 5.5.2.

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5.5.2 Well Environment

If the user/purchaser does not provide the material selection, the functional specification shall specify, as applicable, the following well environment parameters:

a) completion and packer fluid composition, pH, and existence of bromides (Zn, Ca, Na), formates (Cs, K, Na), chlorides (K, Ca, Na), and acetates (Cs);

b) mud type, mud density, and pH;

c) aromatic and aliphatic solvents where present (type/amount);

d) inhibitor treatments (type, concentration, and pH):

— oxygen scavenger systems;

— emulsifier systems;

— continuous or batch treatment;

— chemical composition of fluid exposures;

— duration and temperature of exposure.

e) produced fluid information;

NOTE Produced fluids such as oil, gas, water, water cut, and concentrations of CO_2 and H_2S.

f) injected fluid information;

NOTE Injected fluids such as water, pH, inhibitors, and oxygen levels.

g) NACE service environmental and metallurgical limits.

5.5.3 Material Designation

5.5.3.1 If the user/purchaser chooses to specify a service environment for metallic materials, the following designations may be used:

— standard service;

— NACE service;

— NACE service flow-wetted type 1 components;

— NACE service internally wetted type 1 components;

— NACE service exposed type 1 components.

NACE MR0175 requirements only apply to metallic materials; consideration should be given to nonmetallic materials separately.

5.5.3.2 Metallic material selection may be made for a group of components using the following designations:

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— flow-wetted components;

— internally wetted components;

— exposed components;

— other components.

5.5.4 Material Evaluation

The user/purchaser may specify material testing on metallic materials (see 6.3.3.2.2).

The user/purchaser may specify compound evaluation on nonmetallic materials (see 6.3.3.3.4).

5.6 Design Validation

The user/purchaser shall specify the required design validation grade. This specification provides nine design validation grades (V6-R to V0-R), as defined in 6.5, including two high pressure high temperature (HPHT) design validation grades (V3-HR and V0-HR) covered by Annex B that may be selected by the user/purchaser. Seven legacy validation grades (V6-V0) are provided in Annex A and may be selected by the user/purchaser.

NOTE Annex E provides information for validation of maximum initiation pressure for hydrostatically set products.

5.7 Quality Control

The user/purchaser shall specify the required quality level. This specification provides three quality levels (QL3, QL2, and QL1) of quality control, as defined in 7.4. When no quality level is selected by the user/purchaser, see 7.4.

6 Technical Specification

6.1 General

The supplier/manufacturer shall prepare a technical specification that conforms to the requirements defined in the functional specification. If the technical specification does not fully meet the functional requirements, the supplier/manufacturer shall identify the differences to the user/purchaser. The supplier/manufacturer shall also provide the user/purchaser with the product data sheet, as detailed in 7.2.3.

6.2 Technical Characteristics

The following criteria shall be met.

a) The product shall set and seal in the tubing or casing, without the need for a designed receptacle or profile, and remain set until the product is removed or retrieved. Exceptions to this are the effects of casing or tubing failure.

b) While set and in service, the product shall perform in accordance with the supplier/manufacturer technical specification.

c) Where applicable, the product shall not compromise well intervention operations.

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6.3 Design Requirements

6.3.1 General

Products in the scope of this specification shall be designed and developed under a quality management system in conformance with API Q1.

Products conforming to this specification shall be manufactured to the same supplier/manufacturer requirements and acceptance criteria as those of the same size, type and model product that was validated.

6.3.2 Design Documentation

Design of products manufactured to this specification shall include documentation of those designs. This documentation shall include the following:

a) design requirements;

b) analysis methods;

c) calculations.

This documentation should also include the following, as applicable:

d) assumptions;

e) comparison with previous designs or operating history of similar products;

f) manufacturing drawings and specifications;

g) design reviews;

h) physical testing results (such as design validation testing).

6.3.3 Materials

6.3.3.1 General

Materials and/or the service environment designation (see 5.5.3.1) being provided shall be stated by the supplier/manufacturer and shall conform to the functional specification.The supplier/manufacturer shall have documented specifications for all materials, and all materials used shall conform to the supplier/manufacturer-documented specifications. Materials specifications and/or procedures shall be approved by a qualified person.

All components/materials used in tested or delivered equipment, except common hardware that do not affect the performance (such as nuts, bolts, set screws, and spacers), shall be verified as conforming to documented requirements.

When the user/purchaser specifies NACE service, the metallic materials shall conform to ANSI/NACE MR0175/ISO 15156.

6.3.3.2 Metals

6.3.3.2.1 Specifications

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The supplier/manufacturer specifications shall define the following:

a) chemical composition limits;

b) material condition;

NOTE Material condition can include heat treatment, cold working, etc.

c) mechanical property limits, one or more as applicable:

1) tensile strength;

2) yield strength;

3) elongation;

4) hardness;

5) Charpy impact toughness.

The mechanical properties shall be determined by the test methods listed in Table 1 or by an equivalent international standard.

Table 1—Parameters for Metals

Parameter	Standards
Tensile strength	ASTM A370
Yield strength	ASTM A370
Elongation	ASTM A370
Hardness	ASTM E10, ASTM E18, ISO 6506-1, ISO 6507-1, or ISO 6508-1
Charpy impact toughness	ASTM A370

6.3.3.2.2 Mechanical Testing

When mechanical testing is required by the user/purchaser, the test sample shall be from the same heat of material and experience the same thermomechanical processing along with the raw material used to manufacture the component it qualifies.

NOTE 1 Test sample may be a sacrificial test piece or prolongation.

NOTE 2 If remelted, the same heat refers to the remelted heat.

6.3.3.2.3 Heat Treatment

The heat treatment process parameters shall be defined in a heat treatment procedure. Hardness testing is the only mechanical property test required after stress relieving.

NOTE API 20H provides general guidance for batch heat-treating process qualification.

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6.3.3.3 Nonmetals

6.3.3.3.1 General

The supplier/manufacturer-documented specifications for nonmetallic compounds shall include:

a) characteristics critical to the performance of the product;

b) handling and storage requirements;

c) labeling requirements, including:

— cure date;

— batch number;

— compound identification;

— shelf life or expiration date.

For packing elements, tensile strength and hardness shall be included in the specification.

The elastomeric and thermoplastic parameters shall be determined by the test methods listed in Table 2 for elastomers and Table 3 for thermoplastics, or by an equivalent international standard. The specification shall state if the parameters are measured on actual components.

Table 2—Parameters for Elastomeric Materials

Parameter, as Applicable	Standards
Tensile strength	ASTM D1414 or ASTM D412
Tensile modulus	ASTM D1414 or ASTM D412
Elongation	ASTM D1414 or ASTM D412
Compression set	ASTM D395 or ASTM D1414
Density	ASTM D297
Hardness	ASTM D2240 or ASTM D1415

Table 3—Parameters for Thermoplastic Materials

Parameter, as Applicable	Standards
Tensile strength (at either break or yield, as applicable)	ASTM D638 or ASTM D1708
Elongation (at either break or yield, as applicable)	ASTM D638 or ASTM D1708
Hardness	ASTM D2240

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6.3.3.3.2 Compound Selection

The supplier/manufacturer shall have a documented procedure that provides for the selection of nonmetallic material types and the specific compounds as approved to the supplier/manufacturer specification(s) for use in product designs.

The documented procedure(s) shall, as a minimum, address:

a) functional requirements;

b) technical specifications;

c) material type and compound history of use;

d) geometric component design;

e) chemical stability of materials in well fluids.

Records of material type and compound selection shall become a portion of the design documentation (see 7.2).

6.3.3.3.3 Bond Strength Validations

For component designs where the bond strength of a nonmetallic material is determined by the supplier/manufacturer to be integral to performance, the acceptance criteria shall be defined and the strength of the bonding interface shall be validated with a representative bond test. The bond test for elastic materials shall conform to the requirements of ASTM D429 or an equivalent supplier/manufacturer referenced testing program that includes measured acceptance criteria.

6.3.3.3.4 Environmental Evaluation of Nonmetallic Materials

If required by the user/purchaser, nonmetallic materials shall be evaluated as agreed upon between the user/purchaser and supplier/manufacturer. Records of agreed evaluation shall be maintained.

NOTE The ISO 23936 family of standards are commonly referenced standards for evaluating the chemical stability of polymeric materials based on material properties.

6.3.4 Performance Rating

6.3.4.1 General

The supplier/manufacturer shall state the pressure, temperature, and axial performance ratings, as applicable, for the specific products.

For type 1 components, the supplier/manufacturer shall apply a de-rated yield strength for each material, corresponding to the maximum rated temperature. Determination of the temperature de-rated yield strength factor(s) for design shall be conducted following a documented procedure.

NOTE Temperature de-rated yield strength factor(s) is typically determined through statistical analysis of actual test data or reference to industry recognized published data, such as ASME *BPVC* Section II, Part D.

6.3.4.2 Rated Performance Envelope

For products validated to grade V4 through grade V0, grade V4-R through grade V0-R, grade V3-HR, and grade V0-HR, a rated performance envelope is required. The ratings illustrated in the rated performance

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envelope shall be supported by documented validation testing. The rated performance envelope shall be approved by a qualified person.

An example envelope is illustrated in Figure 1.

The area within the lines forming the boundaries defines the maximum rated performance envelope of the product when it is set.

NOTE For some products that do not have axial load ratings, the rated performance envelope may be a straight line.

Rated performance envelopes shall meet the following criteria; required information that is not on the performance envelope shall be on the product data sheet:

a) The product(s) covered by the envelope shall be specified.

b) The validation grade covered shall be specified.

c) The rated performance envelope shall represent the supplier/manufacturer's maximum rating at the maximum rated temperature. The envelope shall be applicable over the entire specified temperature range.

NOTE Low temperature rating validation is addressed in 6.5.6.9, Annex A, and Annex B.

d) The ratings of end connections shall not be considered in the product ratings.

e) Packers with IDs shall be represented with the ID not plugged unless it is specified on the envelope. Bridge plugs are represented with the ID plugged.

f) Shear devices shall be represented at 100 % of their minimum shear value.

g) The minimum and maximum casing or tubing IDs shall be specified. The envelope shall be applicable over the entire specified ID range.

h) The validated temperature range and temperature-cycle range (where temperature cycling is required by the validation grade) shall be specified (see Figure 2 for a graphical representation of temperature range and the temperature-cycle range).

i) Axis and sign conventions shall be oriented as shown in Figure 1.

j) Unless otherwise specified on the envelope, tubing-to-packer loads shall be applied to the top of the product.

k) If more than one graph is displayed with the envelope, a legend shall be included for explanation. For example, various shear device options, plugged, unplugged, location of plug, alternate temperatures, alternate rated IDs, can be displayed.

l) "Above" and "below" on the pressure axis are defined as above and below the product and not internal to the product. If the envelope includes ratings based on pressure internal to the product, this shall be specified on the envelope or illustrated as an additional graphic.

NOTE Annex G includes information on sealing diameters and pressure-induced loads.

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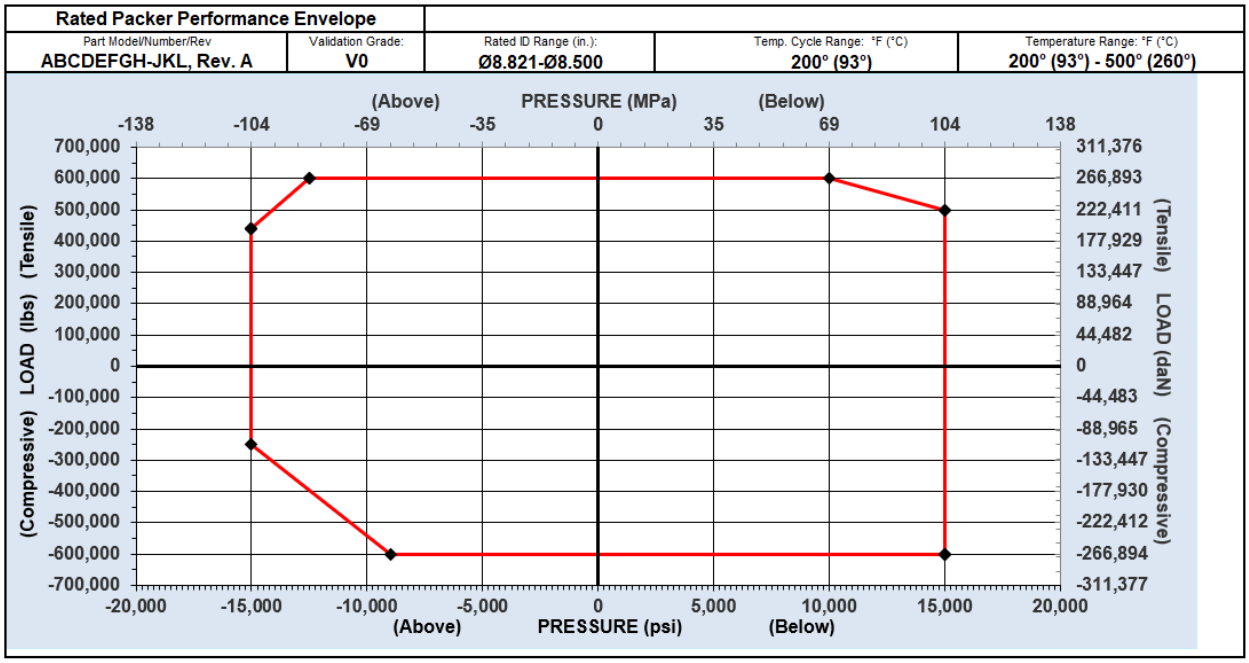

Figure 1—Example of a Rated Performance Envelope

6.3.4.3 Temperature-Cycle Range and Temperature Range

Figure 2 is an illustration of the temperature-cycle range (see 3.33), which is the temperature change over which the product is designed to operate, and the temperature range (see 3.34), which is the range of temperature over which the product is designed to operate.

There shall be only one rated temperature-cycle range and only one rated temperature range for a validated product. If the product cannot be successfully validated using one temperature-cycle range that covers the product's entire temperature range, multiple successful tests shall be performed that cover the maximum and minimum temperatures of the product's temperature range. The rated temperature-cycle range of the product is the smallest of the validated temperature-cycle ranges.

As shown in Figure 2, the temperature-cycle range is applicable anywhere within the product's temperature range.

The information is provided to aid in clarification of the use of these terms and how the design ratings apply.

NOTE The temperature-cycle range is typically determined by the behavior of the product packing element.

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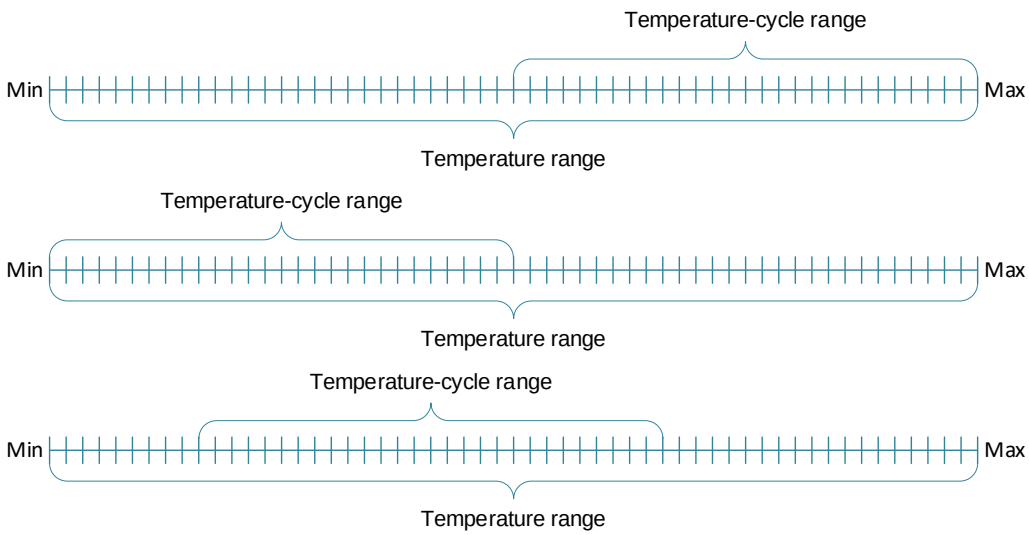

Figure 2—Examples of Temperature-Cycle Ranges and Temperature Ranges

6.4 Design Verification

6.4.1 General

This specification has three design verification methods for which the product shall be supplied based on the validation grade selected, as defined in 6.5. Products shall be verified by one of the following:

a) by conforming to the requirements of 6.4.2 for validation grades V0-R through V6-R; or

b) by conforming to the requirements of Annex A for validation grades V0 through V6 (validated prior to the effective date of the 4th edition); or

c) by conforming to the requirements of Annex B for validation grades V0-HR and V3-HR.

6.4.2 Design Verification Requirements

Design verification shall be performed to ensure that each product design meets the supplier/manufacturer technical specifications. Design verification may include activities such as design reviews, design calculations, and comparing the new design with similar proven designs (see API Q1).

The minimum material condition and minimum material yield strength, including the applicable temperature de-rating, shall be used in the calculations.

Design margin(s) and the mode(s) of stress shall be identified for each type 1 component and other relevant components, as determined by the supplier/manufacturer, using a documented methodology.

If corrosion or corrosion/erosion allowances are included in the design, the design verification and validations shall consider these allowances.

Verification results shall be approved by a qualified person, and records of the results shall become a portion of the design documentation.

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Products that were previously verified in accordance with prior editions of API 11D1 that are being considered to meet the requirements of validation grades V0-HR through V6-R shall be evaluated against the requirements of 6.4.2. Additional verification shall be performed as necessary, with results documented and approved by a qualified person.

EXAMPLE If a V3-H product from API 11D1, 3rd edition is evaluated against the requirements of V3-HR and found to be in conformance, this evaluation is then documented and approved, and the product is designated as V3-HR from the 4th edition.

6.5 Design Validation Requirements

6.5.1 General

This specification has 16 grades of design validation for which the product shall be supplied. Products shall be validated by one of the following and shall be supplied to at least the design validation grade specified:

a) by conforming to the requirements of 6.5 for validation grades V0-R through V6-R; or

b) by conforming to the requirements of Annex A for validation grades V0 through V6 (validated prior to the effective date of the 4th edition); or

c) by conforming to the requirements of Annex B for validation grades V0-HR and V3-HR.

There are nine new 4th edition validation grades:

— V6-R: supplier/manufacturer defined;

— V5-R: liquid test;

— V4-R: liquid test plus axial loads;

— V3-R: liquid test plus axial loads plus temperature cycling;

— V2-R: gas test plus axial loads;

— V1-R: gas test plus axial loads plus temperature cycling;

— V0-R: gas test plus axial loads plus temperature cycling plus zero bubble acceptance criterion;

— V3-HR: validation testing for liquid HPHT service per Annex B;

— V0-HR: validation testing for gas HPHT service per Annex B.

Products that were previously validated in accordance with prior editions of API 11D1 that are being considered to meet the requirements of the 4th edition validation grades (V0-HR through V6-R) shall be evaluated against the 4th edition requirements, with additional validation performed as necessary and results documented and approved by a qualified person.

EXAMPLE If a V3-H product from API 11D1, 3rd edition is evaluated against the requirements of V3-HR and found to be in conformance, this evaluation is then documented and approved, and the product is designated as V3-HR from the 4th edition.

Products without axial load ratings may be validated without axial loading; however, all validation grades are applicable.

Products qualified to higher grades of design validation are qualified for the lower grades of design validation in accordance with Table 4.

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The seven validation grades for legacy products are as follows:

— V6: supplier/manufacturer defined;

— V5: liquid test;

— V4: liquid test plus axial loads;

— V3: liquid test plus axial loads plus temperature cycling;

— V2: gas test plus axial loads;

— V1: gas test plus axial loads plus temperature cycling;

— V0: gas test plus axial loads plus temperature cycling plus zero bubble acceptance criterion.

Table 4—Design Validation Grade Hierarchy, 4th Edition

Design Validation Grade	Grades Covered
V0-HR	V0-HR, V3-HR, V0-R, V0, V1-R, V1, V2-R, V2, V3-R, V3, V4-R, V4, V5-R, V5, V6-R and V6
V3-HR	V3-HR, V3-R, V3, V4-R, V4, V5-R, V5, V6-R and V6
V0-R	V0-R, V0, V1-R, V1, V2-R, V2, V3-R, V3, V4-R, V4, V5-R, V5, V6-R and V6
V1-R	V1-R, V1, V2-R, V2, V3-R, V3, V4-R, V4, V5-R, V5, V6-R and V6
V2-R	V2-R, V2, V4-R, V4, V5-R, V5, V6-R and V6
V3-R	V3-R, V3, V4-R, V4, V5-R, V5, V6-R and V6
V4-R	V4-R, V4, V5-R, V5, V6-R and V6
V5-R	V5-R, V5, V6-R and V6
V6-R	V6-R and V6

Table 5—Design Validation Grade Hierarchy Legacy Products, Annex A

Design Validation Grade	Grades Covered
V0	V0, V1, V2, V3, V4, V5, and V6
V1	V1, V2, V3, V4, V5, and V6
V2	V2, V4, V5, and V6
V3	V3, V4, V5, and V6
V4	V4, V5, and V6
V5	V5 and V6
V6	V6

Products validated to grade V5-R through grade V0-HR shall not be rated for use in casing or tubing sizes and masses (weights) that can have a maximum ID larger than the nominal or as-measured fixture ID up to the maximum allowable tolerance, whichever is greater, used in the validation test [refer to 6.5.2 m)]. The supplier/manufacturer may determine the corresponding casing or tubing size(s) and weight(s) dimensions and ratings for the product.

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NOTE Testing in test fixtures is performed to validate the performance of the product and does not simulate actual casing or tubing conditions such as ovality, straightness, surface finish, or wear.

Special features, which are specific components or subassemblies that provide additional functional capability not validated in the defined tests, shall be identified and validated to their rated limits through documented procedures and acceptance criteria.

The supplier/manufacturer shall document all parameters and results of the evaluations that demonstrate conformance to the validation grade.

6.5.2 Common Validation Requirements

The following apply to product validation testing grade V5-R through grade V0-HR.

a) The validation-tested product shall conform to the requirements of Section 7 (except 7.2.2, 7.2.3, and 7.3) and a minimum of QL3.

b) Testing shall be conducted by qualified person(s). The results shall be approved by a qualified person other than the person performing the test. These records shall become part of the design documentation and included in the validation test report (see 6.5.6).

c) The product shall be set utilizing procedures, methods, and tools identified in referenced supplier/manufacturer procedures.

d) Time period for stabilization at each test step is at the discretion of the supplier/manufacturer.

e) Recorded temperature measurements shall be representative of the product as installed within the test fixture.

f) Gas bubble detection shall be at atmospheric pressure.

g) Additional test points are at the discretion of the supplier/manufacturer or can be specified by the user/purchaser without invalidating the required test points.

h) Products having shear-release features shall be tested at their maximum rated shear load. For safety, the shear device may be replaced with a stronger shear device that can adequately withstand the maximum shear load.

i) Contingency setting methods shall be validated to documented supplier/manufacturer procedures and acceptance criteria.

j) The supplier/manufacturer-specified methods to retrieve the retrievable-type products shall be used at the end of the test. The release loads required to remove the product shall be measured and recorded.

k) Repositionable products shall undergo supplemental validation testing that includes resetting and testing in accordance with the requirements and acceptance criteria of the supplier/manufacturer.

l) For packers, axial loads shall be applied to the top of the packer. For bridge plugs, the location and direction of the applied axial loads shall be documented and noted on the performance envelope. When performing validation testing, pressure-induced loads into the packer from the test fixture configurations shall be considered and compensated for in the product testing.

   Applied axial loads shall be in addition to the pressure-induced loads.

   Pressure-induced loads from above shall be calculated using the cross-sectional area from the fixture ID to the nominal tubing OD or documented seal diameter for products that are directly connected to the tubing, and from the fixture ID to the minimum sealing ID for products with internal sealing surfaces (bores).

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Pressure-induced loads from below shall be calculated using the cross-sectional area from the fixture ID to the nominal tubing OD or documented seal diameter for products directly connected to the tubing, and from the fixture ID to the minimum sealing ID for products with internal sealing surfaces (bores).

NOTE Annex G includes information on sealing diameter and pressure-induced loads.

m) Test fixture:

1) Validation testing shall be performed within a test fixture that is designed to have no OD plastic deformation at the planned test or proof test pressures.

NOTE This fixture simulates supported casing or tubing to validate the performance of the product. Unsupported casing or tubing application are outside the scope of this specification and can require analysis and/or additional testing.

2) The fixture nominal ID shall be the maximum casing or tubing ID, and the fixture nominal ID tolerance shall be a maximum of ± 0.76 mm (± 0.030 in.).

NOTE Annex F provides information on determining maximum and minimum test fixture IDs.

3) Inflatable packing elements are energized to form a seal by applying fluid pressure directly to the element. Products with inflatable packing elements shall be tested horizontally; centralization at one end of the test fixture is acceptable.

4) Products with no anchoring devices or anchoring devices that hold in one direction may be restrained by the test fixture to prevent movement in the unanchored direction(s).

Table 6 defines the type and requirements for allowable test media.

Table 6—Test Media

Media	Requirement
Liquid	Use a liquid test medium of water, with or without additives, or hydraulic oil. The density shall be less than 1100 kg/m^3 (68.67 lb/ft^3). Liquid shall be visibly free from particulate matter or other material.[a]
Gas	Use a gas test medium of air, nitrogen, or other gas or mixture of gases.
[a] Particulate matter and other material can conceal a small leak that would otherwise be evident.	

6.5.3 Validation Test Pressure Reversal Sequences

Validation test pressure reversal sequences as used in 6.5.6 are defined as follows.

One pressure reversal shall be achieved by either of the following sequences:

— above to below; or

— below to above.

Two pressure reversals shall be achieved by either of the following sequences:

— above to below to above; or

— below to above to below.

Three pressure reversals shall be achieved by either of the following sequences:

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— above to below to above to below; or

— below to above to below to above.

6.5.4 Validation Test Procedure

The supplier/manufacturer shall develop procedures for validation testing. These procedures shall be documented and referenced with revision level or included in the final report of the results. The procedures shall include pre- and post-test inspection activities and identify critical areas to be inspected.

Validation testing shall be discontinued if the product fails to perform within the limits specified, except, when such failure(s) is determined to be the result of a failure with the test facility or test fixture and the failure and its correction do not affect the validity of the test results. Failures in the test facility or test fixture and justification for validity of test results shall be included in the final report of the results.

6.5.5 Measuring and Monitoring Equipment

Measuring and monitoring equipment used during the validation testing process shall be calibrated in accordance with the requirements of 7.4.15.

All applied pressures are defined as gauge unless otherwise specified and shall be recorded on time-based equipment.

Axial loads and applied temperatures shall be recorded on time-based equipment.

Where pressure is used to generate an axial load, it is acceptable to record pressure in lieu of load.

6.5.6 Validation Test Requirements

6.5.6.1 General

The steps within each test shall be performed in the order shown below.

6.5.6.2 Grade V6-R—Supplier/Manufacturer Defined

The supplier/manufacturer shall define the requirements, validation methods, and acceptance criteria.

6.5.6.3 Grade V5-R—Liquid Test

The supplier/manufacturer shall adhere to the following test parameters and criteria in Table 7 for conformance to this validation grade. The test media shall be liquid per Table 6.

Table 7—Grade V5-R—Liquid Test

Step	Procedure and Acceptance Criteria	Data to Be Recorded
a)	Record test data as specified and perform pre-test inspection.	— Validation test number — Date — Description of test media — Measured fixture ID — Product identification — Inspection test results
b)	Set product with the minimum rated setting force or pressure (± 10 %) at or above maximum rated temperature.	— Actual temperature — Setting force or pressure

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