

Liner Hanger Equipment

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Introduction

This specification has been developed by users/purchasers and suppliers/manufacturers of liner hanger systems and related equipment as defined herein and is intended for use in the petroleum and natural gas industry worldwide in order to give requirements and information to both parties in the selection, manufacture, testing, and use. Further, this document addresses the minimum requirements with which the supplier/manufacturer is to comply so as to claim conformity with this document.

This specification has been structured with two types of liner hanger systems (conventional and expandable) and two types of activation mechanisms for conventional liner hanger systems (mechanical-set and hydraulic-set).

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

There are three quality grades. Quality grade QL3 is the minimum grade and aligns with supplier/manufacturer-defined quality requirements. Quality grade QL2 is an increased level of quality and generally allows the sampling of components to verify quality requirements are met. Quality grade QL1 is the highest grade provided.

There are three design validation grades for products. Design validation grade V3 is the minimum grade and aligns with supplier/manufacturer-defined product validation. Design validation grade V2 requires testing with liquid as a test medium, while validation grade V1 requires testing with nitrogen.

There are three design validation grades for systems. System design validation grade VS3 is the minimum grade and aligns with the supplier/manufacturer-defined validation methods. System design validation grade VS2 requires system testing with liquid as a test medium, while validation grade V1 requires system testing with nitrogen. Grades VS2 and VS1 can be achieved by testing an entire system, or by combining individual validated products.

Annexes A, B, C, D, and G are informative requirements, where Annexes E, F, and H are normative.

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

Users of this specification should be aware that requirements beyond those outlined in this document may 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. Where an alternative is offered, it is the responsibility of the supplier/manufacturer to identify any variations from this specification.

Liner Hanger Equipment

1 Scope

This specification provides requirements for conventional and expandable liner systems, including liner hangers, liner packers, liner hanger packers, tie-back/polished-bore receptacles (TBR/PBRs), seal assemblies, setting adaptors/sleeves, and running/setting tools as defined herein for use in the oil and natural gas industry. This specification provides minimum requirements for the functional specification and technical specification, including design, design verification and validation, materials, quality control, documentation and data control, repair, shipment, and storage.

Products covered by this specification apply only to applications within a conduit. Installation and field maintenance are outside the scope of this specification. Also not covered in this specification are casing crossover subs, expandable tubulars and expandable connections, end connections to the liner, cementing aids, liner wiper plugs and drill pipe darts, landing collars, float equipment, wellhead/casing hanger, sub-mudline suspension equipment, and cementing heads. Products covered by other API specifications are not in the scope of this specification.

Requirements for the API Monogram program are contained in Annex A.

This specification includes normative Annexes E, F, and H and informative Annexes A, B, C, D, and G.

2 Normative References

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

API Recommended Practice 5C5, 4th Edition, *Procedures for Testing Casing and Tubing Connections*

API Specification 5B, *Threading, Gauging, and Thread Inspection of Casing, Tubing, and Line Pipe Threads*

API Specification 5CT, *Specification for Casing and Tubing*

API Specification 5L, *Specification for Line Pipe*

API Specification 7-2, *Specification for Threading and Gauging of Rotary Shouldered Thread Connections*

API Specification 11D1, *Packers and Bridge Plugs*

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

API Technical Report 5C3, *Calculating Performance Properties of Pipe Used as Casing or Tubing*

ANSI/NACE MR0175 ¹, *Petroleum and Natural Gas Industries—Materials for Use in H₂S-Containing Environments in Oil and Gas Production*

ASME Boiler and Pressure Vessel Code ² (BPVC), *Section VIII: Rules for Construction of Pressure Vessel—Division 1, UW-40: Procedures for Post-weld Heat Treatment*

¹ NACE International, 15835 Park Ten Place, Houston, Texas 77084, www.nace.org.

² American Society of Mechanical Engineers, Two Park Avenue, New York, NY 10016-5990, www.asme.org.

ASME Boiler and Pressure Vessel Code (BPVC), Section IX: Welding and Brazing Qualifications

ASNT RP-SNT-TC-1A³, *Personnel Qualification and Certification in Nondestructive Testing*

ASQC H1331⁴, *Zero Acceptance Number Sampling Plans, Fifth Edition*

ASTM A370⁵, *Standard Test Method and Definitions for Mechanical Testing of Steel Products*

ASTM A388, *Standard Practice for Ultrasonic Examination of Steel Forgings*

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

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

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

ASTM D785, *Standard Test Method for Rockwell Hardness of Plastics and Electrical Insulating Materials*

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

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

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

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

ASTM E8/E8M, *Standard Test Methods for Tension Testing of Metallic Materials*

ASTM E10, *Standard Test Method for Brinell Hardness of Metallic Materials*

ASTM E18, *Standard Test Methods for Rockwell Hardness of Metallic Materials*

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

ASTM E23, *Standard Test Method for Notched Bar Impact Testing of Metallic Materials*

ASTM E111, *Standard Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus*

ASTM E140, *Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness*

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

ASTM E213, *Standard Practice for Ultrasonic Testing of Metal Pipe and Tubing*

ASTM E384, *Standard Test Method for Microindentation Hardness of Materials*

³ American Society for Nondestructive Testing, PO Box 28518, 1711 Arlingate Lane, Columbus, OH 43228-0518, www.asnt.org.

⁴ American Society for Quality, 600 North Plankinton Avenue, Milwaukee, WI 53203, www.asq.org.

⁵ American Society for Testing and Materials, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, www.astm.org.

ASTM E428, *Standard Practice for Fabrication and Control of Metal, Other than Aluminum, Reference Blocks Used in Ultrasonic Testing*

ASTM E709, *Standard Guide for Magnetic Particle Testing*

ISO 527-1⁶, *Plastics Determination of tensile properties Part 1: General principles*

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

ISO 6506 (All Parts), *Metallic materials—Brinell hardness test*

ISO 6507 (All Parts), *Metallic materials—Vickers hardness test*

ISO 6508 (All Parts), *Metallic materials—Rockwell hardness test*

ISO 6892-1, *Metallic materials—Tensile testing—Part 1: Method of test at room temperature*

ISO 6892-2 *Metallic materials—Tensile testing—Part 2: Method of test at elevated temperature*

ISO 9000, *Quality management systems—Fundamentals and vocabulary*

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

ISO 18265, *Metallic materials—Conversion of hardness values*

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

3 Terms, Definitions, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the terms and definitions given in ISO 9000 and the following apply.

3.1.1

assembly

Product comprising more than one component.

3.1.2

barrier

Obstacle or impediment to flow and/or pressure.

3.1.3

base design

Design of a specific size, type, and model of liner equipment that has passed the validation requirements and meets the requirements of this specification.

3.1.4

common hardware

Nontraceable purchased items such as fasteners, washers, spacers, and various types of set screws.

⁶ International Organization for Standardization, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, www.iso.org.

3.1.5**component**

The individual part of a product.

3.1.6**compound**

Combination of constituent elements of the formulation of a nonmetallic material from a particular supplier.

3.1.7**conduit**

Casing, tubing, or liner, either metallic or nonmetallic.

3.1.8**conventional liner hanger**

Product that typically uses a slip/cone mechanism that is typically activated mechanically or hydraulically down hole to suspend the liner in the host conduit/casing. It does not require plastic deformation of the body.

3.1.9**conventional liner system**

Liner system that typically uses a slip/cone mechanism that is activated mechanically or hydraulically to suspend the liner into the host conduit/casing and may have annular sealing device and TBR/PBR.

3.1.10**design validation**

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

3.1.11**design verification**

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

3.1.12**drift diameter**

Minimum inside diameter (ID) of a tube, product, or component, expressed as the outside diameter (OD) of the drift used during assembly inspection.

3.1.13**end connection**

Thread or other mechanism that connects equipment to liner or casing.

3.1.14**environment**

Set of conditions to which the product is exposed.

3.1.15**equipment**

Products or systems to which this document is applicable.

3.1.16**expandable connection**

Threaded connection that is designed to be expanded by radial deformation as part of the expansion process for the expandable tubular.

3.1.17**expandable liner hanger**

Product that uses radial plastic deformation of the body down hole to suspend the liner in the host conduit/casing.

3.1.18**expandable liner system**

Liner system that typically uses radial plastic deformation to suspend the liner into the host conduit/casing and may have an annular sealing device and TBR/PBR.

NOTE This definition excludes solid expandable tubular.

3.1.19**expandable tubular**

A length of conduit that is designed to be expanded by radial deformation.

3.1.20**extrusion gap**

Radial gap between the sealing ID and the OD immediately adjacent to the sealing element.

3.1.21**functional specification**

Features, characteristics, process conditions, boundaries, and exclusions defining the performance and use requirements of the products or systems.

3.1.22**functional test**

Test performed to confirm proper operation of liner equipment.

3.1.23**hanging capacity**

Maximum load capacity of a liner hanger supported inside the host casing/conduit.

3.1.24**heat treatment****heat treating**

Controlled heating or cooling of materials for the purpose of changing mechanical properties.

3.1.25**heat-traceable**

Traceable to a unique heat treatment.

3.1.26**hold down**

Integral component of liner system that limits upward motion of the product or system.

3.1.27**host casing**

Casing into which a liner product or system is installed.

3.1.28**hydraulic set liner hanger**

Liner hanger that uses hydraulic pressure internal to the liner hanger to cause the hanger to function.

3.1.29**informative**

(Information) intended to enlighten the user/purchaser or supplier/manufacturer, without containing requirements.

3.1.30**integrated liner system**

Liner system consisting of a single mandrel/tubular device that combines the functions of two or more products.

3.1.31**internal connection**

Threaded connection integral to or between products of liner systems that are subjected to axial loads and pressures.

3.1.32**job-lot traceable**

(Material or components) having undergone the same process or series of processes and being traceable to one batch of material.

3.1.33**landing collars**

Accessory to the liner string that is used to receive the liner wiper plug.

NOTE Landing collars may also contain a ball seat shearing device.

3.1.34**liner**

Casing string that does not extend to the top of the well or to the wellhead.

3.1.35**liner hanger**

A device used to attach or hang a liner from the internal wall of a previously set casing/conduit string.

3.1.36**liner hanger packer**

Product that contains both liner hanger capabilities and packer capabilities in which both capabilities are activated simultaneously.

3.1.37**liner packer**

Product with a packer element and optional load supporting capability used to seal the annulus between a liner or casing and the previously installed casing.

3.1.38**liner system**

Two or more liner products that are combined to perform a designated function(s).

3.1.39**machined-bore test fixture**

Tubular test fixture machined to a specific ID dimension and which may or may not be machined on the OD.

3.1.40**manufacturing**

Equipment supplier/manufacturer process and action necessary to provide finished component(s), assembly(ies), and related documentation that fulfill the requests of the user/purchaser and meet the standards of the supplier/manufacturer.

3.1.41**mechanical set liner hanger**

Liner hanger that uses either mechanical manipulation of the work string or a hydraulic activated running tool to cause the hanger to function, and that contains no potential pressure leak path between the ID and the OD of the liner hanger.

3.1.42**model**

Equipment with unique components and operating characteristics that differentiate it from other equipment of the same type.

3.1.43**mode of loading**

Means or methods of applying mechanical loads to a system or component that creates a stress or strain.

3.1.44**normative**

(Information or procedures) mandatory for the user/purchaser or supplier/manufacturer to comply with this specification.

3.1.45**operating temperature range**

Specified minimum and maximum temperatures over which the product is designed to operate.

3.1.46**packer**

Device with a packer element used for blocking fluid (liquid or gas) communication through the annular space between conduits by sealing off the space between them.

3.1.47**packer element**

Device preventing passage (i.e. communication) of liquid and/or gas between the annulus of the liner system and the host casing.

3.1.48**packoff**

Device which creates a seal between the running tool and the ID of the liner in order to provide hydraulic integrity between the liner running tool and the liner system.

3.1.49**performance envelope**

Graphical illustration of combined effect of pressure and axial load at maximum rated temperature.

3.1.50**polished-bore receptacle, tie-back receptacle**

Device with a designed internal diameter (ID) sealing surface for receiving a seal assembly.

3.1.51**pressure reversal**

Change in the direction of the pressure differential.

3.1.52**product**

One or more components within a liner system that when assembled provides defined functions.

NOTE Examples include: liner hangers, liner packers, seal assemblies, and TBR/PBRs.

3.1.53**product family**

Group of products whose configurations, sizes, materials, and applications are sufficiently similar enough that identical design methodologies can be used to establish the design parameters for each product within the family.

3.1.54**quadrant**

Each of four parts of a performance envelope divided by two lines at right angles to each other.

3.1.55**qualified person**

Individual or individuals 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.

3.1.56**rated pressure**

Pressure limit as defined by the supplier/manufacturer for external, internal, and barrier differentials.

3.1.57**rework**

The process of returning a product to its fully operational state through the replacement of qualified components and/or manufactured activities.

3.1.58**running/setting tool(s)**

Specialized device(s) used to install liner systems in a well.

3.1.59**scaled design**

Variation of a base design that has been validated by scaling in accordance with the limitations and requirements of this specification.

3.1.60**sealing element**

Component that prevents passage of liquid and/or gas across the interface in which it is placed.

3.1.61**seal assembly****seal stem**

Mandrel containing one or more seal units to be installed in a designed receptacle.

3.1.62**seal unit**

Device which provides pressure integrity between the TBR/PBR and mandrel of the seal assembly.

3.1.63**second-trip packer**

Liner packer that is run in combination with a seal assembly that seals in the previously run liner to seal the annulus between the liner and the previously installed casing.

3.1.64**setting sleeve****setting adaptor**

Integral component of the liner system that provides an attachment interface to the running tool.

3.1.65**size**

Relevant dimensional characteristics (nominal casing/liner) of the product as defined by the supplier/manufacturer.

3.1.66**special feature**

Specific component or subassembly that provides a functional capability that is not validated during the validation test.

NOTE Special features may include items such as ambient chambers, fluid-charged chambers, equalization flow, lock open, exercise, communication devices, mechanisms that ensure fail safe activation, control fluid redirection features, or electronic sensing and control. This list of special features is not fully inclusive.

3.1.67**stabilization**

The act of achieving a defined acceptance range for applied test parameters that conforms to the supplier/manufacturer's documented requirements and occurs prior to testing hold periods.

3.1.68**strain factor**

Ratio of the calculated strain divided by the maximum allowable strain in a given component.

3.1.69**stress factor**

Ratio of the calculated maximum stress divided by the minimum yield strength in a given component.

3.1.70**stress relieving**

Controlled heating of material to a predetermined temperature for the purpose of reducing any residual stresses.

3.1.71**sub-mudline suspension equipment**

Equipment that supports the casing string below the mudline.

3.1.72**substantive design change**

Change to the design, identified by the supplier/manufacturer as affecting the performance of the product in the intended service condition.

3.1.73**supplier/manufacturer**

Principal agent in the design, fabrication, and furnishing of equipment, who chooses to comply with this specification.

3.1.74**supported casing**

API 5CT-compliant casing that is externally supported, either mechanically or hydraulically, to limit stress levels during validation.

3.1.75**temperature cycle range**

Specified change in temperature over which the product is validated.

NOTE The temperature cycle range is applicable anywhere within the product's operating temperature range. See Figure 11.

3.1.76**tie-back receptacle, polished-bore receptacle**

Device with a designed internal diameter (ID) sealing surface for receiving a seal assembly.

3.1.77**Type 1 component**

Component that isolates pressure and/or may be loaded in tension as the result of axial loads on the product.

3.1.78**Type 2 component**

Component that does not meet the criteria of a Type 1 component.

3.1.79**validation test**

Test performed to qualify a particular size, type, and model of equipment or system for a specific validation grade.

3.1.80**wellhead/casing hanger**

Equipment that supports the casing string in the wellhead.

3.2 Abbreviations

AOQL	average outgoing quality limit
AQL	acceptance quality limit
COC	certificate of compliance
FEA	finite element analysis
ID	inside diameter
MTR	material test report
MYS	minimum yield strength
NDE	non-destructive examination
OD	outside diameter
PBR	polished-bore receptacle
PMI	positive material identification
QC	quality control
QMS	quality management system
TBR	tie-back receptacle
TOL	top of liner
D	pipe outside diameter
ID_{max}	maximum internal diameter
L	the specified unsupported length of applied pressure
P_c	pressure for yield strength collapse
P_i	internal pressure at yield for a thin tube
S_E	equivalent stress
S_Y	minimum yield strength
t	pipe wall thickness (also defined as minimum pipe thickness 6.6.13.2)

4 General Information

4.1 Product and System Illustrations

Figures 1 through 10 illustrate typical products and liner systems.

/

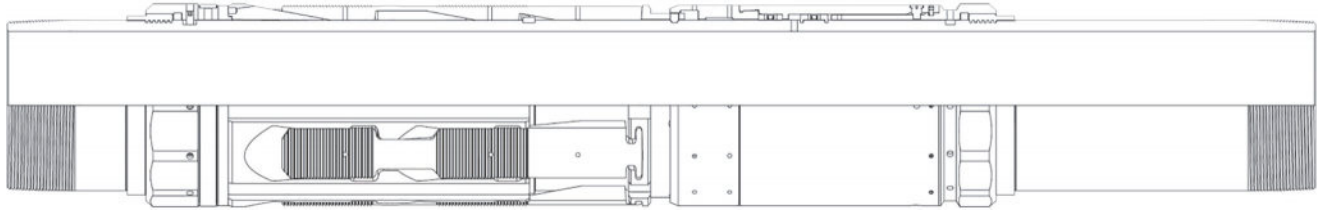


Figure 1—Hydraulic Set Hanger (Conventional)

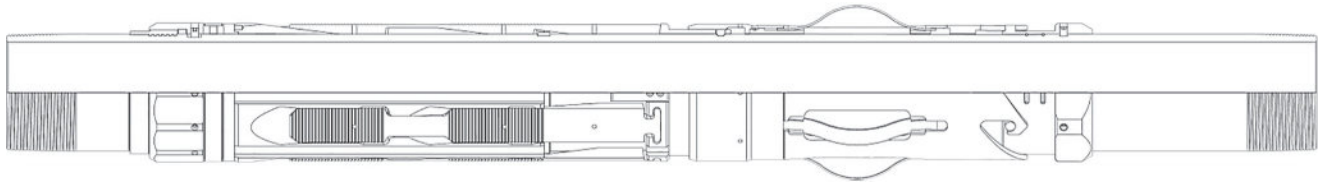


Figure 2—Mechanical Set Hanger (Conventional)

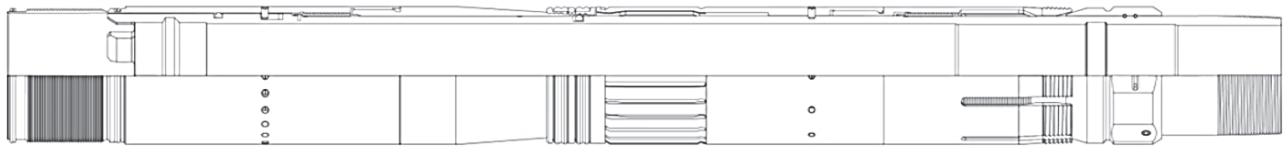


Figure 3—Liner Packer (Conventional)

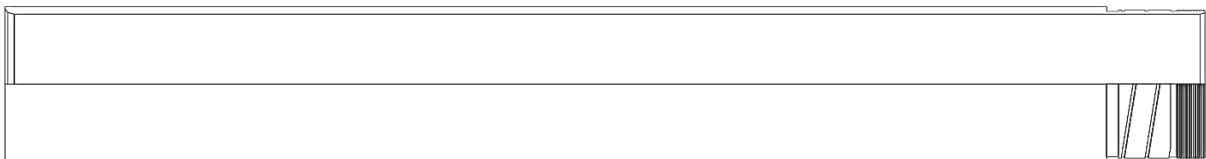


Figure 4—TBR/PBR

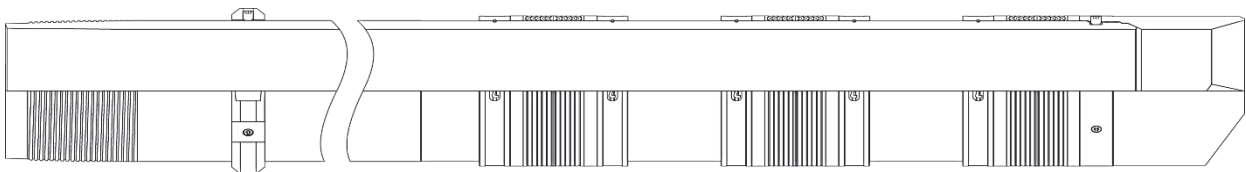


Figure 5—Seal Assembly

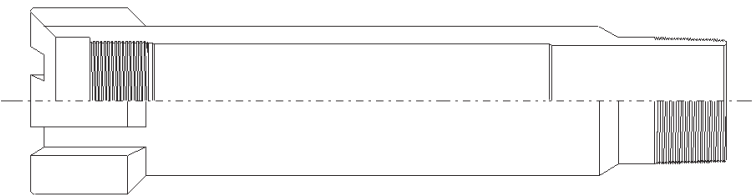
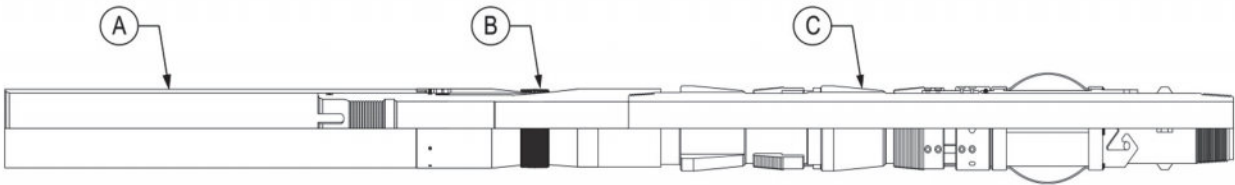


Figure 6—Setting/Adaptor Sleeve



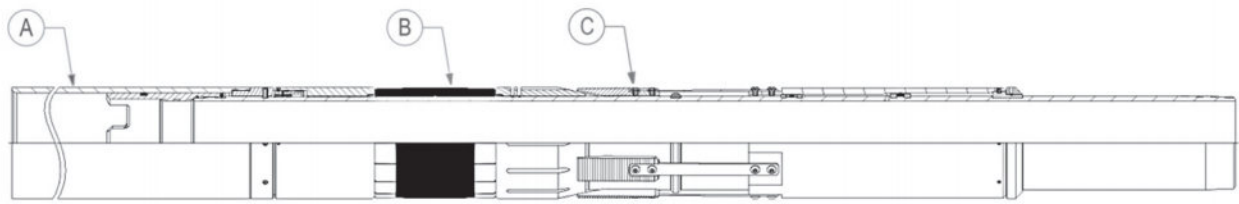
- Key
- A PBR/TBR
 - B Liner packer
 - C Liner hanger

Figure 7—Mechanical Set Liner Hanger System, Activated by Pipe Manipulation



- Key
- A PBR/TBR
 - B Liner packer
 - C Liner hanger

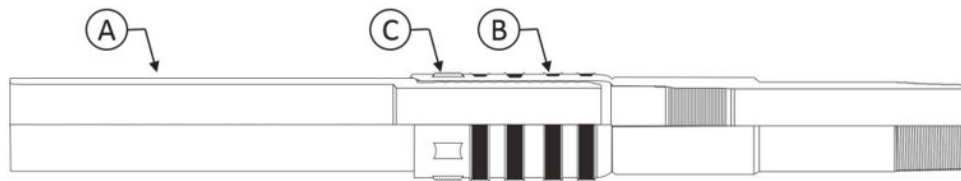
Figure 8—Mechanical Set Liner Hanger System, Activated by Hydraulic Running Tool



Key

- A PBR/TBR
- B Liner Packer
- C Liner Hanger

Figure 9—Hydraulic Set Liner Hanger System



Key

- A PBR/TBR
- B Liner packer
- C Liner hanger

Figure 10—Expandable Liner Hanger System

5 Functional Requirements

5.1 General

The user/purchaser shall prepare a functional specification for ordering products or systems that conform to this specification and specify the following requirements and operating conditions, as applicable, and/or identify the supplier/manufacturer's specific product or system. These requirements and operating conditions may be conveyed by means of text, dimensional drawing, data sheet, or other suitable documentation. An example of a functional specification checklist is provided in Annex B.

The user/purchaser may select a system type of conventional or expandable. For a conventional system type, the user/purchaser may select a setting method of hydraulic or mechanical.

5.2 Product Types

The user/purchaser may specify the following products of a liner system:

- a) liner hanger;
- b) liner packer;

- c) liner hanger packer;
- d) running/setting tools;
- e) seal assembly;
- f) setting sleeve/adaptor;
- g) tie-back receptacle / polished-bore receptacle (TBR/PBR).

5.3 Functional Characteristics

The user/purchaser may specify the following functional characteristics:

- a) type of hanger and packer actuation method (hydraulic, mechanical, or expandable);
- b) rotating capability while running liner in the hole;
- c) rotating or pipe movement capability while cementing;
- d) circulating capability.

5.4 Well Parameters

The user/purchaser may specify the following well parameters:

- a) well location (land, platform, subsea);
- b) size, mass (weight), grade, material, and connections of the casing, liner, and drill pipe;
- c) casing architecture, trajectory, deviations, maximum dogleg severity;
- d) restrictions through which the liner equipment and accessories shall pass;
- e) wellbore fluids type and composition.

5.5 Operational Parameters

The user/purchaser may specify the following operational parameters:

- a) maximum rated pressure, for both external, internal and barrier differential pressures;
- b) operating temperature range, for both maximum and minimum operational conditions;
- c) temperature cycle range (see Figure 11);
- d) loading conditions, including combined loading (pressures, tension/compression, torque) and the corresponding temperature limits expected.

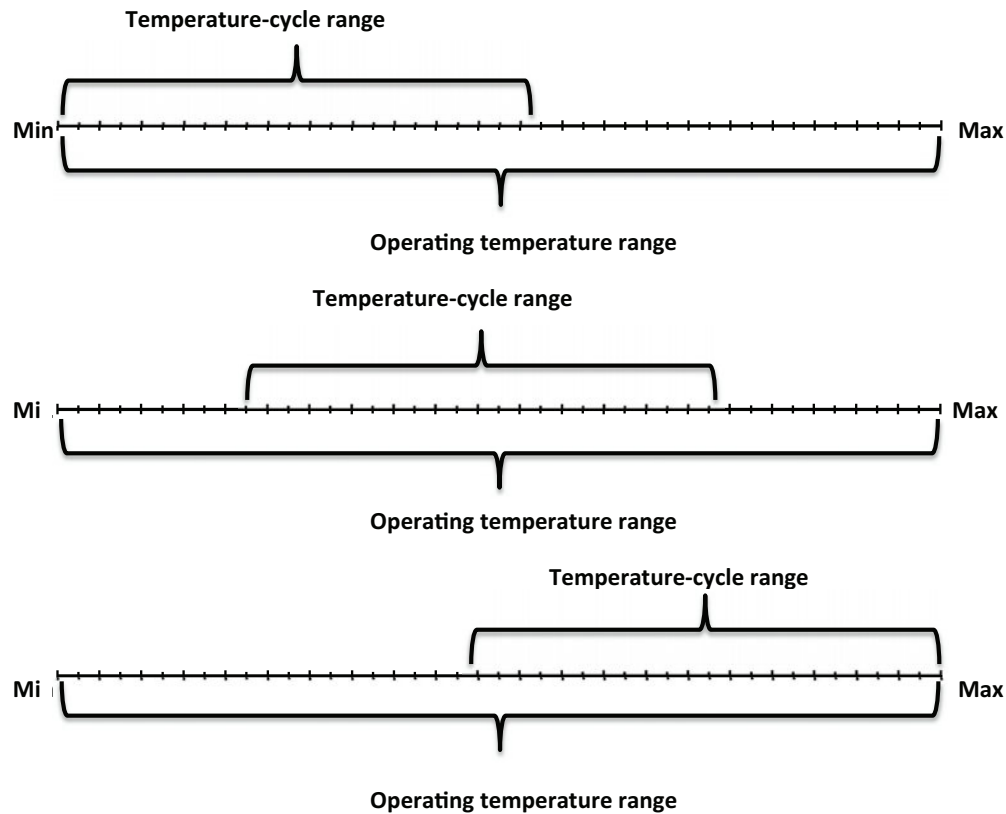


Figure 11—Temperature Cycle Range Illustration

NOTE The operating temperature range (see 3.1.44) is acknowledged to be the range over which an elastomer compound was determined to be effective; both in its ability to compress and set at low temperatures as well as its ability to block an extrusion gap and be resistant to extrusion failure at higher temperatures. The temperature cycle range (see 3.1.75) is similarly known to be the extreme temperature fluctuation that the elastomer can tolerate while still maintaining an adequate amount of sealing force at lower temperatures.

5.6 Environmental Compatibility

In cases where the user/purchaser has access to corrosion property data and/or research that is applicable to the functional specification, the user/purchaser shall state which material(s) have the ability to perform as required.

In cases where the user/purchaser elects to use materials specified by the supplier, the user/purchaser shall provide the necessary environmental conditions to enable the proper selection of materials for the environment.

The user/purchaser shall specify any requirements for environmental conditions during transportation, storage, and at surface prior to and during deployment.

5.7 Compatibility with Related Equipment

To ensure that the liner system is compatible with the application and related well equipment, the user/purchaser shall specify, where applicable, the following:

- a) liner size, weight, grade, drift, connection;

- b) casing size, weight, grade, drift, connection in which liner equipment is installed;
- c) configurations of other products and tubulars to be used in conjunction with the liner system.

5.8 User/Purchaser Validation Grade Selection

5.8.1 General

The user/purchaser shall select one design validation grade for each liner system or product design to be provided.

This specification provides three design validation grades (VS1, VS2, and VS3) for liner systems and three design validation grades (V1, V2, V3) for products as stipulated in 6.6.6.

Products validated to higher grades of design validation are considered validated for the lower grade as stipulated in Table 1. Liner systems validated to higher grades of design validation are considered validated for the lower grade as stipulated in Table 2.

Table 1—Product Design Validation Grade Hierarchy

Design Validation Grade	Grades Covered
V1	V1, V2, V3
V2	V2, V3
V3	V3

Table 2—Liner System Design Validation Grade Hierarchy

Design Validation Grade	Grades Covered
VS1	VS1, VS2, VS3
VS2	VS2, VS3
VS3	VS3

5.8.2 Liner Packers and Liner Hanger Packers

See 6.6.6.1 for validation of products previously validated under API 11D1.

5.9 Quality Grades

The user/purchaser shall select one quality grade for each liner system or product design to be provided. This specification provides three grades of quality (QL1, QL2, and QL3) as stipulated in detail in 7.4.

5.10 Optional Requirements

The user/purchaser may select additional requirements from Annex C for external flow testing.

6 Technical Specification

6.1 General

The supplier/manufacture shall provide the user/purchaser with a technical specification that conforms to the requirements defined in the functional specification of Section 5 or identifies in detail where the variance(s) are offered.

Products and systems produced according to this specification shall be designed and manufactured under a quality management system (QMS) that conforms to a recognized quality management standard such as API Q1 or ISO/TS 29001.

6.2 Technical Characteristics

The following criteria shall be met:

- a) The liner system shall be capable of setting at the specified location and remain so until intentional intervention defines otherwise. If equipped with packer, liner system shall be capable of sealing and remain so until intentional intervention defines otherwise.
- b) While being run, installed, and in service, the liner system shall be capable of performing in accordance with the functional specification.
- c) Where applicable, the liner system shall not compromise well intervention operations.

NOTE Well condition or casing failure may prevent proper operation of liner systems.

6.3 Design Criteria

6.3.1 General

Products shall be designed to meet the design validation and functional specification requirements. Final approval of the design shall be performed and documented by a qualified person(s) of the supplier/manufacturer other than the person who created the original design.

6.3.2 Design Requirements

Documentation of designs and design changes shall include methods, assumptions, formulas, calculations, and design requirements (see 7.2.2). Design requirements shall include, but not be limited to, criteria for size, performance ratings, materials, environment, temperature cycle range and/or operating temperature range, validation grade, and other pertinent requirements upon which the design is based. Final design documentation shall be reviewed and verified by a qualified person other than the individual who created the original design.

Equipment conforming to this specification shall be manufactured to drawings and specifications that do not have substantive design changes from those of the size, type, and model equipment that have passed the applicable validation tests.

The supplier/manufacturer shall establish the following verified performance ratings, as applicable:

- a) internal yield pressure;
- b) collapse pressure;
- c) differential pressure across packer element;
- d) tensile load strength;
- e) compressive strength;
- f) operating temperature range;
- g) hanging capacity;

- h) hold-down capacity;
- i) torque capacity.

The design shall take into account the effects of pressure containment and pressure-induced loads, including forces and loads induced during the running and setting of the system.

Internal connections shall meet or limit the performance rating of the product or system in which the internal connection is used.

6.4 Design Verification

6.4.1 General

Design verification shall be performed using documented procedures to ensure that each product/system design meets the supplier/manufacture's technical specifications and shall include activities such as design reviews, design calculations, physical tests, comparison with similar designs and historical records of defined operating conditions.

Verification results shall be reviewed and approved by a qualified person and records of the review shall become a portion of the design documentation (see 7.2).

6.4.2 Design Analysis

6.4.2.1 General

The equipment shall be analyzed to determine the performance limits. The performance limits of the assembly shall be determined by the component of the design with the highest stress factor (or strain factor for plastically deformed components). The design shall consider all operational loading conditions defined in the functional specification. One of the design analysis methods in 6.4.2.2 shall be used to determine the maximum state of stress of a component. Once the method is selected, it becomes the requirement.

The supplier/manufacture shall identify the Type 1 components of the product or system and the mode of loading. The supplier/manufacture shall calculate the stress level (and strain level for plastically deformed components) in the identified component(s) based upon the worst-case loads in the design requirements.

In the determination of ratings, the minimum acceptable material condition and minimum acceptable material yield shall be used in the calculations. The calculations shall include consideration of the effects of temperature. Tests by the supplier/manufacture shall be conducted in accordance with ASTM E21 or ISO 6892-2 for yield strength and ASTM E111 for modulus of elasticity. Other equivalent national or international standards may be used. Metal mechanical properties derating shall be in accordance with one or more of the following:

- industry recognized published data reviewed and verified by a qualified person;
- data provided by the material supplier;
- data used by the supplier/manufacture.

6.4.2.2 Design Analysis Methods

6.4.2.2.1 Distortion Energy Theory

The distortion energy theory, also known as the von Mises yield criterion, may be used for design calculations for pressure-containing components.

NOTE The distortion energy theory predicts a combined stress that will exceed the material's minimum yield strength; this is also commonly known as von Mises stress. This theory determines a combined stress at a point from the given principal stresses. The von Mises stress predicts failure when the total amount of distortion in a differential cube of material is equivalent to the distortion experienced by the same cube when loaded by a uniaxial force to the yield point.

Rules for the consideration of discontinuities and stress concentrations are beyond the scope of this method and this specification. However, the basic pressure vessel wall thickness may be sized by combining triaxial stresses based on hydrostatic test pressure and limited by the following criterion:

$$S_E \leq S_Y \quad (1)$$

where:

S_E is the maximum allowable equivalent stress at the most highly stressed distance into the pressure vessel wall, computed by the distortion energy theory method;

S_Y is the material-specified minimum yield strength.

6.4.2.2.2 Triaxial Yield and Collapse Equations

API 5C3 provides equations that may be used to derive the triaxial yield and collapse of a cylinder.

6.4.2.2.3 Finite Element Analysis

Finite element analysis (FEA) is a design verification methodology that may be used to predict equipment performance for complex geometry and/or complex loading where conventional verification methodologies are considered incomplete by the design engineer.

NOTE An example FEA method for analyzing a pressure-containing component is described in Annex D.

6.4.2.2.4 Supplier/Manufacturer Defined Analysis

Supplier/manufacturer defined analysis may be used for design calculations for pressure-containing components.

6.4.3 Rated Performance Envelope

A rated performance envelope as specified in 6.7 shall be prepared for systems validated to VS1 or VS2.

For validation grade VS3, a rated performance envelope shall be prepared when requested in the functional specification.

6.5 Materials

6.5.1 General

Materials for each component shall be stated by the supplier/manufacturer and shall be suitable for the environmental conditions specified in the functional specification. The supplier/manufacturer shall have documented specifications for all materials, and materials shall comply with these specifications.

- a) The user/purchaser may specify materials for the specific use and corrosion environment in the functional specification. If the supplier/manufacturer proposes to use another material, the user/purchaser has the option to accept or reject the proposed material alternative. This applies to metallic and nonmetallic components.
- b) Material substitutions from those materials used in the validation-tested liner system or components are allowed without further validation testing. The supplier/manufacturer's selection criteria for these substitutions shall be documented, and the substituted material shall conform to the design, functional, and technical requirements of

this specification. Material substitutions require approval by a qualified person(s) using the methods and practices used to accept the original material, and its supporting documentation shall be retained in accordance with 7.2.1.

- c) Substantive changes to materials (metallic and nonmetallic) that can affect product performance shall be considered in accordance with 6.8.

6.5.2 Metals

6.5.2.1 General

Metallic materials used in the manufacture of liner system components shall meet the requirements in 6.5.2.2 to 6.5.2.3.

6.5.2.2 Specifications

The material specifications shall include:

- a) chemical composition limits;
- b) heat treatment requirements/conditions, as applicable;
- c) mechanical property limits, including as applicable:
 - tensile strength;
 - yield strength (transverse and longitudinal, as applicable);
 - elongation;
 - hardness; and
 - toughness.

6.5.2.3 Additional Requirements

The mechanical properties specified in 6.5.2.2 c) for traceable components shall be verified by tests conducted on a material sample produced from the same heat of material. The material sample shall experience the same heat treatment process as the component it qualifies. The resulting material test report (MTR) shall be approved by supplier/manufacturer's qualified person and retained in accordance with 7.2.

Materials selected for use in sulfide stress cracking environments shall be in accordance with the supplier/manufacturer's documented procedure or as specified by the user/purchaser. Metallic materials specified by supplier/manufacturer used in sulfide stress cracking environments shall meet requirements of ANSI/NACE MR0175.

6.5.3 Nonmetals

6.5.3.1 General

The supplier/manufacturer shall have documented procedures, including acceptance criteria, for evaluations or testing of seal materials or other nonmetals.

6.5.3.2 Sealing System Requirements

Chemical and environmental effects shall be considered for nonmetallic sealing elements in order to determine selection of the seal material. Verification or validation shall establish that the nonmetal sealing element used is

suitable for the specific configuration, environment, and application. The evaluations or tests shall ensure compatibility with the technical and functional requirements and shall consider: mechanical loads, applied pressure, temperature range, design geometry, and sealing environment.

6.5.3.3 Bonding to Substrates

Nonmetallic seal components may be bonded to substrates for additional reinforcement or to perform other functions. The integrity of the bond shall be evaluated in accordance with the supplier/manufacturer's defined methods and acceptance criteria.

Substrate metals shall conform to the requirements for metallic components. Nonmetallic substrates shall conform to the requirements of 6.5.3.4.

6.5.3.4 Nonmetallic Components

The supplier/manufacturer's documented specifications for nonmetallic compounds shall include handling, storage, and labeling requirements, including the cure date, batch number, compound identification, and shelf life appropriate to each compound and shall define those characteristics critical to the performance of the material, such as:

- a) compound type;
- b) mechanical properties, including as a minimum:
 - tensile strength (at break);
 - elongation (at break); and
 - tensile modulus (at 50 % or 100 %, as applicable).
- c) compression set;
- d) durometer hardness.

6.5.4 Welding and Brazing

Welding, including overlays and brazing, shall require the following:

- a) Weld materials and practices not listed in the ASME BPVC Section IX shall be applied using weld procedures qualified in accordance with the methods of ASME BPVC Section IX or equivalent.
- b) Welding and brazing procedure and personnel qualification shall be in accordance with ASME BPVC Section IX or equivalent.
- c) Welding for sour service shall meet the requirements of ANSI/NACE MR0175.

6.6 Design Validation

6.6.1 General

There are two methods of design validations included in this specification: product design validation and liner system design validation. Liner system design validation shall require a performance envelope to be prepared in accordance with 6.7. The validation testing requirements in this specification may not represent all well conditions.

Product design validation results may be used to generate system performance envelopes. Where the intent is to combine product validations to create a system performance envelope, the product validations shall provide the

necessary information to create a system performance envelope as described in 6.7. Validation test results and dimensional inspections results shall be approved by a qualified person other than the person performing them, and validation records shall become a portion of the design documentation.

Products and systems used in validation testing shall be designed and manufactured in accordance with the applicable requirements of Sections 5, 6, and 7.

Any repair or redress of the product or system during validation testing shall require the testing to restart from the beginning.

Liner hanger running/setting tools shall be validated in accordance with Annex E.

Special features which are not validated during validation testing shall be validated in separate tests to their rated limits using documented procedures and acceptance criteria and the results approved by a qualified person.

6.6.2 Procedures

The supplier/manufacture shall develop procedures for conducting design validation. These procedures shall be documented and 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. The supplier/manufacture shall document all parameters and results of the evaluations that demonstrate conformance to the defined validation grade. Validation testing shall be discontinued if the product or system fails to perform within the limits specified except when such failure(s) are determined to be the result of a failure within the test facility or test fixture and that failure and its correction do not affect the validity of the test results.

For validation grade V1, V2, VS1, and VS2, pressure hold shall be a minimum of 15 minutes after stabilization of the test parameters. The time period and limits for stabilization are at the discretion of the supplier/manufacture.

For validation grade V2 and VS2, the test medium shall be liquid. The density shall be less than 1100 kg/m³ (68.67 lb/ft³). Liquid shall be visibly free from particulate matter and/or other material that have the potential of plugging potential small leaks.

For validation grade V1 and VS1, the test medium shall be nitrogen.

NOTE Filler material may be used to reduce the amount of nitrogen. The filler material shall not interfere with the validation procedure or test result.

For more information on product and system validation grades, refer to 6.6.6.

6.6.3 Personnel

Preparation, testing, and approval of results shall be conducted by qualified person(s).

6.6.4 Measuring and Monitoring Equipment

Measuring and monitoring equipment used during the validation process shall be calibrated in accordance with the requirements of 7.5.

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

Recorded temperature measurements shall be representative of those of the product as it is installed in the test fixture.

Gas leakage shall be measured in graduated cylinders at atmospheric pressure.

6.6.5 Test Report

A test report shall be prepared for each design validation and approved by qualified person(s) other than those who prepared the report; it shall be retained as part of the design validation records for the product (as described in 7.2.2). The report shall include the following information as a minimum:

- a) validation test performed;
- b) a description of the tested item, which shall include size, type, model, unique identifier;
- c) test facility name, location, and person performing the testing;
- d) date(s) of validation testing conducted;
- e) test schematic;
- f) procedures used and records demonstrating compliance to the established procedures, including acceptance criteria and discussion of those results;
- g) remarks (describing any non-specified equipment or procedures requested by manufacturer, unusual conditions observed during test, etc.);
- h) additional information required by the applicable annex requirements or test procedure describing the testing, as applicable;
- i) results of specific pre- and post-evaluations such as: visual inspections, drift testing, and test fixture surface condition;
- j) summary of results, including a discussion whether or not the test was successful;
- k) approvals and date of the report.

NOTE Records may be electronic or hardcopy.

6.6.6 Product and System Validation Grades

6.6.6.1 General

This specification defines three grades of design validation for products and three grades of design validation for liner systems. Each product or system design shall be validated to the grade selected by the user/purchaser.

Products and systems shall be supplied to at least the design validation grade specified. In the event a validation grade is not selected by the user/purchaser, Grade V3 or VS3 shall apply.

Each product or system tested shall pass all requirements within the limits specified, to the defined acceptance criteria, and with documentation and approval of the results.

Pre-test and post-test dimensional inspection of critical operational areas, as determined by the supplier/manufacturer, shall be conducted, documented, and maintained by the supplier/manufacturer.

The supplier/manufacturer shall have on file material specifications and drawings that show all the applicable dimensions and tolerances of components contained in the validation-tested product or system.

Liner packers and liner hanger packers previously validated under API 11D1 prior to release of this specification shall be considered validated to the grades shown in Table 3.

Table 3—Validation Grade Comparison

API 11D1	API 19LH
V0, V0-H	V1, V2, V3
V1, V3, V3-H	V2, V3
V2, V4, V5, V6	V3

Liner packers and liner hanger packers previously validated under API 11D1 shall meet all other applicable requirements in this specification.

6.6.6.2 Product Validation Grades

The product validation grades are the following:

- V3: supplier/manufacturer-defined;
- V2: liquid test plus axial loads and temperature cycle range;
- V1: nitrogen test plus axial loads and temperature cycle range.

NOTE 1 Temperature cycle range does not apply to mechanical hanger load testing defined in 6.6.8.4 and mechanical set liner hanger combined load and pressure testing defined in 6.6.9.4.1.

NOTE 2 Seal assembly validation grades are included in 6.6.14.

Products validated to higher grades of design validation may be considered qualified for the lower grades of design validation in accordance with Table 1.

6.6.6.3 System Validation Grades

The system validation grades are the following:

- VS3: supplier/manufacturer-defined;
- VS2: liquid test plus axial loads and temperature cycle range;
- VS1: nitrogen test plus axial loads and temperature cycle range.

Liner systems qualified to higher grades of design validation may be considered qualified for the lower grades of design validation in accordance with Table 2.

6.6.7 Design Validation Scaling

6.6.7.1 General

Scaling may be used to validate a variation of a validated product of the same size, type, and model in the same product family. Products that have been previously validated to grades V2 or V1 can be scaled. The product validated by scaling (child design) shall carry the same validation grade as the validated product (parent design) that the scaled design was based upon.

Sealing elements shall be scaled in accordance with the requirements and limitations of 6.6.7.4.

The supplier/manufacturer shall not use scaling to validate products with higher pressure ratings, higher axial load ratings, a higher maximum operating temperature, a lower minimum operating temperature, a larger temperature cycle range, or larger rating envelope than the validated product. Product designs containing substantive changes shall comply with 6.8.2.

In addition, if the scaled product interacts with host casing, the supplier/manufacturer shall establish the maximum stress within the host casing used to validate the parent design and in the host casing of the child design. The mode of stress and same method of calculation(s)/verification(s) shall be applied to the host casing of the parent design and the child design. The stress factor of the child design host casing shall not exceed the stress factor of the parent design host casing.

Each scaled product requires evaluation and justification. Design scaling shall be approved by a qualified person and records of the results shall become a portion of the design documentation indicating a scaled design.

Product designs containing substantive changes shall comply with 6.8.2.

6.6.7.2 Non-plastically Deformed Components

The supplier/manufacturer shall establish the maximum stress within the previously validated design Type 1 components and in the same components of the scaled design. The mode of loadings and same method of calculation(s)/verification(s) shall be applied to the identified components of the base design and the scaled design. For the Type 1 component with the highest design stress factor, the scaled design's stress factors shall not exceed the stress factor of the same component of the validated design.

6.6.7.3 Plastically Deformed Components

For Type 1 components which are designed to permanently deform in service, the supplier/manufacturer shall establish the maximum strain factor within the previously validated design components and in the same components of the scaled design. The mode of loadings and same method of calculation(s)/verification(s) shall be applied to the identified components of the base design and the scaled design. The scaled design's strain factor shall not exceed the strain factor of the same component of the validated design. Additional limitations of product design scaling are defined in each of the individual product validation sections.

6.6.7.4 Sealing Element Scaling Requirements

Scaling of sealing element validation results or verifications shall comply with 6.6.7.1 and shall be documented and approved by a qualified person. Packer element scaling is not covered by this section, as it is specifically addressed in 6.6.10.5 and 6.6.11.5. Metallic sealing elements cannot be validated by scaling.

Limitations on scaling of nonmetallic seal components are:

- a) Allowable variation in size shall be within $\pm 5\%$ of the nominal seal bore diameter and/or cross section thickness of the validated design.
- b) Supplier/manufacturer's material specifications of scaled sealing element shall meet the material specification which was used for the validated sealing element.
- c) Loading mode (including any support mechanisms) shall be identical for the scaled and the validated sealing element.
- d) Stress factors of metallic components surrounding the scaled nonmetallic sealing element shall not exceed those of the validated metallic components at the rated working pressure.

- e) Sealing element nominal extrusion gap and tolerances on seal gland and bore shall not be greater than that allowed by the validated design.
- f) Stress calculation method(s) shall be identical for the scaled sealing element and the validated sealing element.

6.6.8 Liner Hanger Load Design Validation

6.6.8.1 General

Validation of liner hangers shall meet the requirements of 6.6.8 and 6.6.9 as applicable per the specified validation grade.

Where the liner hanger includes rotational capability after setting, testing and validation shall be performed in accordance with Annex F.

6.6.8.2 Test Fixtures

The test fixture shall be either:

- unsupported casing conforming to API 5CT or API 5L for OD greater than 508 mm (20 in); or
- unsupported machined-bore (casing equivalent) test fixture with mechanical properties conforming to API 5CT or API 5L, as appropriate. A machined-bore test fixture may be machined on the OD and/or ID.

An MTR, which verifies the yield strength, shall be available for the test fixture. The test fixture hardness and dimensions shall be measured and documented by the supplier/manufacturer as conforming to the design requirements. Test fixture options are summarized in informative Table 4.

Table 4—Test Fixture Options

Test Fixture Description	6.6.8 Hanger Load Design Validation	6.6.9 Liner Hanger Combined Load and Pressure Design Validation	6.6.10 Liner Packer Design Validation	6.6.11 Liner Hanger Packer Design Validation
Unsupported API casing	Yes	Yes	Yes	Yes
Supported API casing	No	Yes ^a	Yes	Yes ^a
Unsupported machined-bore (casing equivalent) test fixture	Yes	Yes	No ^b	No ^b
Supported machined-bore (casing equivalent) test fixture	No	Yes ^a	No ^b	No ^b
Machined-bore (max casing ID) test fixture	No	Yes ^a	Yes	Yes ^a
^a This is only applicable to combined load and pressure testing where the liner hanger load has been previously established in unsupported casing or unsupported machined-bore (casing equivalent) test fixture. ^b Testing of packer element in machined-bore fixture is limited to maximum API ID.				

For tests conducted in an unsupported casing:

- The liner hanger shall be tested in the lightest weight casing specified (for a liner hanger designed to operate in a range of casing weights of the same nominal size).
- The liner hanger shall be tested in the size/weight combination that results in the largest nominal ID (for liner hanger designed to operate in a range of casing weights and sizes).

- Casing ID shall be a minimum of 0.5 % greater than nominal ID for casing conforming to API 5CT and a minimum of nominal ID for casing conforming to API 5L, as determined by measurements in at least two points at 90-degree separation. Casing shall not be machined on the ID except as needed for fixturing in the area not used by the liner hanger.

For tests conducted in unsupported machined-bore (casing equivalent) test fixture:

- The liner hanger shall be tested in a machined-bore test fixture with the ID equivalent to the lightest weight casing specified (for liner hanger designed to operate in a range of casing weights of the same nominal size).
- The liner hanger shall be tested in the size/weight combination that results in the largest nominal ID (for liner hanger designed to operate in a range of casing weights and sizes).
- Fixture ID shall be a minimum of 0.5 % greater than nominal ID, as determined by measurements in at least two points at 90-degree separation.
- The fixture OD shall conform to API 5CT or API 5L for the given size. Fixture OD shall be a maximum of 0.5 % greater than nominal OD.

NOTE 1 API 5CT allows sizes and weights other than those published in the standard to be supplied by agreement between the user/purchaser and supplier/manufacture. See Section 8.2 in API 5CT, 10th edition [1].

NOTE 2 The intent of assigning test fixtures to products:

- Testing in casing is preferred.
- If casing is not available, testing in casing equivalent is allowed for some products.
- If testing of packer element cannot be performed in casing due to pressure limitation or casing availability, machined-bore fixture with max ID can be used.

6.6.8.3 Validation Grade V3

The supplier/manufacture shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 and support the stated product ratings and capabilities.

6.6.8.4 Validation Grades V2 and V1 Test Procedure

The supplier/manufacture shall conduct validation in accordance with the following steps:

- 1) Install hanger in fixture.
- 2) Activate hanger to engage slips in accordance with supplier/manufacture's procedures.
- 3) Increase the temperature to maximum rated temperature or higher, and run entire test at or above the maximum rated temperature.
- 4) Apply increasing axial load until supplier/manufacture-defined rated load is achieved. Applied load hold period is 5 minutes minimum, with no movement allowed after stabilization.

6.6.8.5 Acceptance Criteria for V1 and V2

The acceptance criteria for liner hanger load design validation are as follows:

- a) Casing shall not be split, breached, or perforated through the wall.

- b) The product shall drift at its specified drift diameter during the test or post-test condition. The drift shall conform to API 5CT.
- c) Conduct post-test inspection according to supplier/manufacturer procedure.
- d) Prepare test report according to 6.6.5.

6.6.9 Liner Hanger Combined Load and Pressure Design Validation

6.6.9.1 General

The design validation of liner hangers shall meet the requirements of 6.6.8 and 6.6.9 as applicable per the specified validation grade. Test medium requirements are specified in 6.6.2.

6.6.9.2 Test Fixtures

The test fixture shall be one of the following:

- unsupported casing as described in 6.6.8.2;
- unsupported machined-bore (casing equivalent) test fixture as described in 6.6.8.2;
- supported casing conforming to API 5CT or API 5L for OD greater than 508 mm (20 in);
- supported machined-bore (casing equivalent) test fixture with mechanical properties conforming to API 5CT or API 5L, as appropriate. A machined-bore test fixture may be machined on the OD and/or ID; or
- machined-bore (max casing ID) test fixture with an ID conforming to equation (2).

An MTR, which verifies the yield strength, shall be available for the test fixture. The test fixture hardness and dimensions shall be measured and documented by the supplier/manufacturer as conforming to the design requirements.

Pressure-induced loads into the liner hanger from the test fixture configurations shall be considered and off-set in the product testing. Any compensated load shall be documented.

The following apply for tests conducted in supported or unsupported casing:

- The liner hanger shall be tested in the lightest weight casing specified (for liner hangers designed to operate in a range of casing weights of the same nominal size).
- The liner hanger shall be tested in the size/weight combination that results in the largest nominal ID (for liner hangers designed to operate in a range of casing weights and sizes).
- Casing ID shall be a minimum of 0.5 % greater than nominal ID for casing conforming to API 5CT and minimum of nominal ID for casing conforming to API 5L, as determined by measurements in at least two points at 90-degree separation. Casing shall not be machined on the ID except as needed for fixturing in the area not used by the liner hanger.
- The validation procedures in 6.6.8 and 6.6.9 can be combined into a single procedure. Where validation testing includes both load testing and combined load with pressure testing into a single testing program, the test fixture shall conform to both the requirements of 6.6.8 and 6.6.9.

NOTE 1 API 5CT allows sizes and weights other than those published in the standard to be supplied by agreement between the user/purchaser and supplier/manufacture. See 8.2 in API 5CT, 10th edition [1].

For tests conducted in unsupported or supported machined-bore (casing equivalent) test fixture:

- For liner hanger designed to operate in a range of casing weights of the same nominal size, the liner hanger shall be tested in a machined-bore test fixture with the ID equivalent to the lightest weight casing specified.
- For liner hanger designed to operate in a range of casing weights and sizes, the liner hanger shall be tested in the size/weight combination that results in the largest nominal ID.
- Fixture ID shall be a minimum of 0.5 % greater than nominal ID, as determined by measurements in at least two points at 90-degree separation. The fixture OD shall conform to API 5CT or API 5L for the given size. Fixture OD shall be a maximum of 0.5 % greater than nominal OD.

NOTE 2 API 5CT allows sizes and weights other than those published in the standard to be supplied by agreement between the user/purchaser and supplier/manufacture. See Section 8.2 in API 5CT, 10th edition [1].

The following apply for tests performed in a machined-bore (max casing ID) test fixture:

- The machined-bore test fixture shall have an ID equivalent to the maximum ID of the lightest weight casing of the specified weight range, as determined by equation (2). The tolerance on the ID shall be ± 0.76 mm. (0.030 in.)

$$ID_{max} = \sqrt{OD_{max}^2 - 0.965(OD_{nom}^2 - ID_{nom}^2)} \quad (2)$$

where

OD_{nom} = Nominal OD of casing;

ID_{nom} = Nominal ID of casing;

$OD_{max} = OD_{nom} \times 1.01$. (3)

- For liner hanger designed to operate in a range of casing weights and sizes, the liner hanger shall be tested in the size/weight combination that results in the largest maximum casing ID.
- The test fixture OD is defined by supplier/manufacture.

NOTE 3 ID_{max} as calculated by Equation (2) may differ from actual maximum ID of casing for non-standard sizes. Equation (2) is to calculate the test fixture's ID.

6.6.9.3 Validation Grade V3

The supplier/manufacture shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 and support the stated product ratings and capabilities.

6.6.9.4 Validation Grade V2

6.6.9.4.1 Mechanical Set Liner Hangers

6.6.9.4.1.1 Validation Procedure

The supplier/manufacture shall adhere to the following test parameters and criteria for conformance to this validation grade:

- 1) Install hanger in fixture.
- 2) Activate hanger to engage slips, as in accordance with supplier/manufacturer's procedures.
- 3) Increase the temperature to maximum rated temperature or higher, and run entire test at or above the maximum rated temperature.
- 4) Apply maximum rated internal pressure.
- 5) Remove internal pressure.
- 6) Apply maximum rated external pressure.
- 7) Remove external pressure.
- 8) Apply combined load and pressure to test envelope intersection points, one point minimum per quadrant, as applicable. The load shall not exceed maximum hanging load established in 6.6.8.

6.6.8.4 and 6.6.9.4 can be combined when the unsupported API casing is used for the test fixture. To perform this combined testing, Step 4 in 6.6.8.4 shall be inserted between Step 3 and Step 4 in the procedure above.

6.6.9.4.1.2 Acceptance Criteria

The acceptance criteria for mechanical set liner hangers shall be as follows:

- a) Pressure hold period shall be 15 minutes minimum, with no more than 1 % reduction in the maximum rated pressure over the hold period, after sufficient time has been allowed for stabilization.
- b) Applied load hold period shall be 5 minutes minimum, with no movement allowed after stabilization. Casing shall not be split, breached, or perforated through the wall.
- c) Combined load and pressure test hold period is 15 minutes minimum, with no movement and no more than 1 % reduction in the maximum rated pressure over the hold period, after sufficient time has been allowed for stabilization. Casing shall not be split, breached, or perforated through the wall.
- d) The product shall drift at its specified drift diameter during the test or post-test condition. The drift shall conform to API 5CT.
- e) Conduct post-test inspection according to supplier/manufacturer procedure.
- f) Prepare test report according to 6.6.5.

6.6.9.4.2 Hydraulic Set Liner Hangers

6.6.9.4.2.1 Validation Procedure

The supplier/manufacturer shall adhere to the following test parameters and criteria for conformance to this validation grade:

- 1) Install hanger in fixture. Increase temperature to the maximum operating temperature minus one half of the temperature cycle range ($\pm 10\%$).
- 2) Pressure hanger internally to activate hanger in accordance with supplier/manufacturer's procedures. Setting pressure shall be within the specified range.
- 3) Increase the temperature to maximum rated temperature or higher, and run entire test, except temperature cycling, at or above the maximum rated temperature.
- 4) Apply maximum rated internal pressure.
- 5) Remove internal pressure.
- 6) Apply maximum rated external pressure.
- 7) Remove external pressure.
- 8) Apply combined load and pressure to test envelope intersection points, one point minimum per quadrant as applicable. The load shall not exceed maximum hanging load established in 6.6.8.
- 9) Reduce temperature by the minimum of the temperature cycle range value.
- 10) Repeat Step 6 and one envelope point from Quadrant IV (see 6.7).

6.6.8.4 and 6.6.9.4 can be combined when the unsupported API casing is used for the test fixture. To perform this combined testing, Step 4 in 6.6.8.4 shall be inserted between Step 3 and Step 4 in the procedure above.

6.6.9.4.2.2 Acceptance Criteria

The acceptance criteria for hydraulic set liner hangers are as follows:

- a) Pressure test hold period is 15 minutes minimum, with no more than 1 % reduction in the maximum rated pressure over the hold period, after sufficient time has been allowed for stabilization.
- b) Applied load hold period is 5 minutes minimum, with no movement allowed after stabilization. Casing shall not be split, breached, or perforated through the wall.
- c) Combined load and pressure test hold period is 15 minutes minimum, with no movement and no more than 1 % reduction in the maximum rated pressure over the hold period, after sufficient time has been allowed for stabilization. Casing shall not be split, breached, or perforated through the wall.
- d) The product shall drift at its specified drift diameter during the test or post-test condition. The drift shall conform to API 5CT.
- e) Conduct post-test inspection according to supplier/manufacturer procedure.
- f) Prepare test report according to 6.6.5.

6.6.9.5 Validation Grade V1

6.6.9.5.1 Mechanical Set Liner Hangers

A V2 validated mechanical set liner hanger without seals or internal connections is considered equivalent to a V1 validated mechanical hanger. The supplier/manufacturer shall adhere to the test parameters and criteria in 6.6.9.4.1 for conformance to this validation grade.

A V2 validated mechanical set liner hanger with seals or internal connections shall be validated according to 6.6.9.4.2 with the exception that the hanger shall be set mechanically, per Step 2 of 6.6.9.4.1.1.

6.6.9.5.2 Hydraulic Set Liner Hangers

6.6.9.5.2.1 Validation Procedure

To qualify the hydraulic set liner hangers to V1, all the following steps shall be performed within the acceptance criteria defined.

- 1) Install hanger in fixture. Increase temperature to the maximum operating temperature minus one half of the temperature cycle range ($\pm 10\%$).
- 2) Pressure hanger internally to activate hanger in accordance with the supplier/manufacturer's procedures. Setting pressure shall be within the specified range.
- 3) Increase the temperature to maximum rated temperature or higher, and run entire test, except temperature cycling, at or above the maximum rated temperature.

NOTE Supplier/manufacturer should consider the effects of explosive decompression during validation testing.

- 4) Apply maximum rated internal pressure.
- 5) Remove internal pressure.
- 6) Apply maximum rated external pressure.
- 7) Remove external pressure.
- 8) Apply combined load and pressure to test envelope intersection points, one point minimum per quadrant as applicable. The load shall not exceed maximum hanging load established in 6.6.8.
- 9) Reduce temperature by the minimum of the temperature cycle range value.
- 10) Repeat Step 6 and one envelope point from Quadrant IV (see 6.7).

6.6.8.4 and 6.6.9.5.1 can be combined when the unsupported API casing is used for the test fixture. To perform this combined testing, Step 4 in 6.6.8.4 shall be inserted between Step 3 and Step 4 in the procedure above.

6.6.9.5.2.2 Acceptance Criteria

The acceptance criteria are as follows:

- a) Pressure hold period shall be 15 minutes minimum, with zero bubbles of nitrogen accumulated in a graduated cylinder over the hold period, after sufficient time has been allowed for stabilization.

- b) Applied load hold period shall be 5 minutes minimum, with no movement allowed after stabilization. Casing shall not be split, breached, or perforated through the wall.
- c) Combined load and pressure test hold period is 15 minutes minimum, with no movement and with zero bubbles of nitrogen accumulated in a graduated cylinder over the hold period, after sufficient time has been allowed for stabilization. Casing shall not be split, breached, or perforated through the wall.
- d) The product shall drift at its specified drift diameter during the test or post-test condition. The drift shall conform to API 5CT.
- e) Conduct post-test inspection according to supplier/manufacturer procedure.
- f) Prepare test report according to 6.6.5.

6.6.10 Liner Packer Design Validation

6.6.10.1 General

Validation of liner packers shall meet the requirements of 6.6.10, as applicable per the specified validation grade.

NOTE 1 See 6.6.6.1 for validation of products previously validated under API 11D1.

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).

Test those products having shear-release features at their maximum rated shear load. For safety, the shear device can be replaced with a stronger shear device that can adequately withstand the maximum shear load.

Special features of the liner packer not validated during this test shall be validated in separate tests to their rated limits using documented procedures and acceptance criteria.

NOTE 2 This test validates liner packers in a non-tied back application. For liner packer validation with seal assembly, see 6.6.13 and 6.6.14.

6.6.10.2 Test Fixtures

The test fixture shall be one of the following:

- supported casing as described in 6.6.8.2;
- unsupported casing as described in 6.6.8.2; or
- machined-bore (max casing ID) test fixture.

If the test fixture is supported, it shall be supported throughout all steps of the test.

An MTR, which verifies the yield strength, shall be available for the test fixture. The test fixture hardness and dimensions shall be measured and documented by the supplier/manufacturer as conforming to the design requirements.

The following apply for tests conducted in supported or unsupported casing:

- For packers designed to operate in a range of casing weights of the same nominal size, the packer shall be tested in the lightest weight casing specified.
- For packers designed to operate in a range of casing weights and sizes, the packer shall be tested in the size/weight combination that results in the largest nominal ID.
- Casing ID shall be a minimum of 0.5 % greater than nominal ID for casing conforming to API 5CT and minimum of nominal ID for casing conforming to API 5L, as determined by measurements in at least two points at 90-degree separation. Casing shall not be machined on the ID, except as needed for fixturing in the area not used by the packer.

NOTE API 5CT allows sizes and weights other than those published in the standard to be supplied by agreement between the user/purchaser and supplier/manufacture. See 8.2 in API 5CT, 10th edition [1].

The following apply for tests performed in machined-bore (max casing ID) test fixture.

- Test fixtures machined from mechanical tube shall have an ID equivalent to the maximum ID of the lightest weight casing of the specified weight range, as determined by Equation (2) in 6.6.9.2. The tolerance on the ID shall be ± 0.76 mm (0.030 in.).
- For packers designed to operate in a range of casing weights and sizes, the packer shall be tested in the size/weight combination that results in the largest maximum casing ID.

Pressure-induced loads into the packer from the test fixture configurations shall be considered and off-set in the product testing. Any compensated load shall be documented.

6.6.10.3 Validation Grade V3

For validation grade V3, the supplier/manufacture shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 and support stated product ratings and capabilities.

6.6.10.4 Test Procedures for V2 and V1

The supplier/manufacture shall adhere to the following test parameters in the order shown and to the criterion for conformance to this validation grade, which are listed in Table 5. Repair or redress of the packer requires validation testing to restart at the beginning.

Table 5—Liner Packer Validation Test Procedure V1 and V2

Step	Procedure and Acceptance Criteria	Data to be Recorded
1	Record test data as specified.	Validation test number and grade Date Part number Serial number Test fixture description and support, if present
2	Conduct pre-test inspection according to supplier/manufacture's procedures.	Dimensional inspection results
3	The packer shall be set using procedures, methods and tools identified in referenced supplier/manufacture procedures. Set the packer at the max operating temperature minus one half of the temperature cycle range ± 10 %. Set the packer with the minimum rated setting force or pressure (± 10 %).	Procedure identification Temperature at set Force/pressure applied to set

Table 5—Liner Packer Validation Test Procedure V1 and V2 (Continued)

Step	Procedure and Acceptance Criteria	Data to be Recorded
4	Adjust the temperature to the maximum operating temperature or higher. Maintain temperature during Step 5 through Step 7.	Temperature during test
5	<p>Apply pressure. Pressure testing to begin with the maximum rated differential pressure applied to the packer element from a direction where the setting load into the element is least boosted or enhanced by the test pressure. Stabilize pressure and temperature in accordance with supplier/manufacturer requirements.</p> <p>Hold applied pressure for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report.</p> <p>Relieve applied pressure, then continue to next step.</p> <p>Acceptance criteria for V2: No more than 1 % reduction in the maximum rated differential pressure over the hold period.</p> <p>Acceptance criteria for V1: Zero bubbles of nitrogen observed over the hold period.</p>	<p>Pressuring during test</p> <p>Measured pressure loss for V2</p>
6	<p>Apply the maximum rated differential pressure to the opposite end of the packer element. Stabilize pressure and temperature in accordance with supplier/manufacturer requirements.</p> <p>Hold applied pressure for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report.</p> <p>Relieve applied pressure, then continue to next step.</p> <p>Acceptance criteria for V2: No more than 1 % reduction in the maximum rated differential pressure over the hold period.</p> <p>Acceptance criteria for V1: Zero bubbles of nitrogen observed over the hold period.</p>	<p>Applied load during test (if applicable)</p> <p>Measured pressure loss for V2</p>
7	<p>Apply the maximum rated pressure to the packer element from a direction where the setting load into the element is least boosted or enhanced by the test pressure. Stabilize pressure and temperature in accordance with supplier/manufacturer requirements.</p> <p>Hold applied pressure for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report.</p> <p>Relieve applied pressure then continue to the next step.</p> <p>Acceptance criteria for V2: No more than 1 % reduction in the maximum rated differential pressure over the hold period.</p> <p>Acceptance criteria for V1: Zero bubbles of nitrogen observed over the hold period.</p>	<p>Pressuring during test</p> <p>Measured pressure loss for V2</p>
8	<p>Test to all the intersection points of the rated performance envelope.</p> <p>Hold applied pressure or combinations of load and pressure for 15 minutes minimum. Stabilize load, pressure, and temperature in accordance with supplier/manufacturer requirements. If no pressure loss is observed, it shall be documented in the test report</p> <p>Relieve applied load and pressure, then continue to the next step.</p> <p>Acceptance criteria for V2: No more than 1 % reduction in the maximum rated differential pressure over the hold period, with no movement allowed after stabilization. Casing shall not be split, breached, or perforated through the wall.</p> <p>Acceptance criteria for V1: Zero bubbles of nitrogen observed over the hold period, with no movement allowed after stabilization. Casing shall not be split, breached, or perforated through the wall.</p>	<p>Applied load during test (if applicable)</p> <p>Measured pressure loss for V2</p>

Table 5—Liner Packer Validation Test Procedure V1 and V2 (Continued)

Step	Procedure and Acceptance Criteria	Data to be Recorded
9	<p>Reduce temperature by a minimum of the temperature cycle range value. Perform a pressure test at or above the maximum rated pressure from a direction where the setting load into the element is least boosted or enhanced by the test pressure. Stabilize pressure and temperature in accordance with supplier/manufacture requirements.</p> <p>Hold applied pressure for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report.</p> <p>Acceptance criteria for V2: No more than 1 % reduction in the maximum rated differential pressure over the hold period.</p> <p>Acceptance criteria for V1: Zero bubbles of nitrogen observed over the hold period.</p>	<p>Temperature during test</p> <p>Pressure during test</p> <p>Measured pressure loss for V2</p>
10	<p>Conduct post-test inspection according to supplier/manufacture's procedures, and prepare test report according to 6.6.5.</p>	<p>Dimensional inspection results</p> <p>Evidence of malfunction(s) or anomalies</p> <p>Test report</p>

Unless otherwise specified by supplier/manufacture, gas pressure-relieving (bleed-down) operations shall be performed at a rate of 0.69 MPa (100 psi) per minute or less when the pressures are less than 10.34 MPa (1500 psi).

6.6.10.5 Limitations of Scaling for Liner Packer Design

Scaling may be used to validate variations in a product family, in accordance with the requirements and limitations of 6.6.7. This applies to products validated to grade V2 or V1, in accordance with 6.6.10.1.

Testing a product design in the largest nominal ID of the ID range of the product design and in the smallest nominal ID of the ID range of the product design validates the product design for all IDs between the two tested sizes.

Packer elements and anti-extrusion components of the scaled product design shall be of the same geometry and materials specification as the validated product design prior to testing.

The supplier/manufacture's specified OD of the component under the packer element(s) of the scaled product design shall be the same as the validated product design prior to testing.

6.6.11 Liner Hanger Packer Design Validation

6.6.11.1 General

Validation of liner hanger packers shall meet the requirements of 6.6.11, as applicable per the specified validation grade.

NOTE See 6.6.6.1 for validation of products previously validated under API 11D1.

Test those products having shear-release features at their maximum rated shear load. For safety, the shear device can be replaced with a stronger shear device that can adequately withstand the maximum shear load.

6.6.11.2 Test Fixture

The test fixture shall be one of the following:

- supported casing, as described in 6.6.8.2;
- unsupported casing as described in 6.6.8.2; or
- machined-bore (max casing ID) test fixture.

An MTR, which verifies the yield strength, shall be available for the test fixture. The test fixture hardness and dimensions shall be measured and documented by the supplier/manufacturer as conforming to the design requirements.

The following apply for tests conducted in supported or unsupported casing:

- For packers designed to operate in a range of casing weights of the same nominal size, the packer shall be tested in the lightest weight casing specified.
- For packers designed to operate in a range of casing weights and sizes, the packer shall be tested in the size/weight combination that results in the largest nominal ID.
- Casing ID shall be a minimum of 0.5 % greater than nominal ID for casing conforming to API 5CT and minimum of nominal ID for casing conforming to API 5L as determined by measurements in at least two points at 90-degree separation. Casing shall not be machined on the ID except as needed for fixturing in the area not used by the packer.

NOTE API 5CT allows sizes and weights other than those published in the standard to be supplied by agreement between the user/purchaser and supplier/manufacturer. See 8.2 in API 5CT, 10th edition [1].

The following apply for tests performed in machined-bore (max casing ID) test fixture:

- Test fixtures machined from mechanical tube shall have an ID equivalent to the maximum ID of the lightest weight casing of the specified weight range as determined by Equation (2) in 6.6.9.2. The tolerance on the ID shall be ± 0.76 mm (0.030 in.).
- For packers designed to operate in a range of casing weights and sizes, the packer shall be tested in the size/weight combination that results in the largest maximum casing ID.

Pressure-induced loads into the packer from the test fixture configurations shall be considered and off-set in the product testing. Any compensated load shall be documented.

6.6.11.3 Validation Grade V3

For validation grade V3, the supplier/manufacturer shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 and support stated product ratings and capabilities.

6.6.11.4 Validation Grades V2 and V1

Liner Hanger Packer shall be validated to 6.6.10.4, and hanging capacity shall be validated to 6.6.8.4. Validation testing shall include testing to the limits and order as defined in the applicable product testing; however, test steps can be combined to effectively achieve the defined testing criteria while minimizing testing repetition. Each of the rated performance envelope intersection points shall be tested.

6.6.11.5 Limitation of Scaling of Liner Hanger Packer Designs

The product design for all IDs between the two tested sizes is validated by the successful validation testing of a product design in the largest nominal ID of the ID range of the product design, and in the smallest nominal ID of the ID range of the product design.

Packer elements and anti-extrusion components of the scaled product design shall be of the same geometry and materials specification as the validated product design prior to testing.

The supplier/manufacturer's specified OD of the component under the packer element(s) of the scaled product design shall be the same as the validated product design prior to testing.

6.6.12 Interface Seal between the TBR/PBR and Packer Body or Setting Adaptor/Sleeve Design Validation

6.6.12.1 General

The performance of these test procedures validates the interface seal between TBR/PBR and packer or setting adaptor/sleeve. It is required for applications using a liner top tie-back system. In designs where an internal connection performs the function of an interface seal, it shall be validated in accordance with 6.6.15.

6.6.12.2 Test Fixtures

The supplier/manufacturer shall document the test fixture configuration and dimension for each validation test performed. An MTR, which verifies the yield strength, shall be available for the test fixture.

Validation testing shall be conducted in a test fixture that is designed and manufactured to the same sealing surface tolerances and dimensions as the production product.

6.6.12.3 Validation Grade V3

For validation grade V3, the supplier/manufacturer shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 and support the stated product ratings and capabilities.

6.6.12.4 Validation Grades V2 and V1

The supplier/manufacturer shall adhere to the following test parameters in the order shown and to the criterion for conformance to this validation grade, which are listed in Table 6.

Unless otherwise specified by supplier/manufacturer, gas pressure-relieving (bleed-down) operations shall be performed at a rate of 0.69 MPa bar (100 psi) per minute or less when the pressures are less than 10.34 MPa (1500 psi).

**Table 6—Interface Seal between TBR/PBR and Packer Body or Setting Adaptor/Sleeve
Validation Test Procedure V1 and V2**

Step	Procedure and Acceptance criteria	Data to be Recorded
1	Record test data as specified.	Validation test number and grade Date Unique identifier
2	Conduct pre-test inspection according to supplier/manufacturer's procedures. Dimensional inspection results shall comply with supplier/manufacturer's requirement.	Dimensional inspection results
3	Adjust temperature of the test fixture to the maximum temperature or higher. Maintain temperature during Step 4 and Step 5.	Temperature during test
4	<p>Apply the maximum rated differential pressure to one side of the seal. Stabilize pressure and temperature in accordance with supplier/manufacturer requirements.</p> <p>Hold applied pressure for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report.</p> <p>Relieve applied pressure then continue to the next step.</p> <p>Acceptance criteria for V2: No more than 1 % reduction in the maximum rated differential pressure over the hold period.</p> <p>Acceptance criteria for V1: Zero bubbles of nitrogen observed over the hold period.</p>	<p>Pressuring during test</p> <p>Measured pressure loss for V2</p>
5	<p>Perform a minimum of two pressure reversals at or above the maximum operating pressures.</p> <p>Hold applied pressures for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report.</p> <p>Relieve applied pressure then continue to the next step.</p> <p>Acceptance criteria for V2: No more than 1 % reduction in the maximum rated differential pressure over the hold period.</p> <p>Acceptance criteria for V1: Zero bubbles of nitrogen observed over the hold period.</p>	<p>Applied load during test (if applicable)</p> <p>Measured pressure loss for V2</p>
6	<p>Reduce temperature by a minimum of the temperature cycle range value.</p> <p>Perform a pressure test at or above the maximum rated pressure.</p>	<p>Temperature during test</p> <p>Pressure during test</p>
7	<p>Hold applied pressures for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report.</p> <p>Acceptance criteria for V2: No more than 1 % reduction in the maximum rated differential pressure over the hold period.</p> <p>Acceptance criteria for V1: Zero bubbles of nitrogen observed over the hold period.</p>	Measured pressure loss for V2
8	<p>Conduct post-test inspection according to supplier/manufacturer's procedures.</p> <p>Prepare test report according to 6.6.5.</p>	<p>Visual inspection results</p> <p>Evidence of malfunction(s) or anomalies</p> <p>Test report</p>

6.6.12.5 Limitations of Scaling for Interface Seal

Limitations on scaling for interface seal between the TBR/PBR and packer body or setting adaptor/sleeve are contained in 6.6.7.

6.6.13 TBR/PBR Design Validation

6.6.13.1 General

Each TBR/PBR design shall be validated by analysis or by testing. TBR/PBR products made up of multiple segments containing an internal thread connection shall be validated with testing in accordance with 6.6.13.3 unless axial loads are present. When axial loading is present in the TBR/PBR internal thread(s), the TBR/PBR shall be validated in accordance with 6.6.16.

6.6.13.2 Design Validation by Analysis (Grades V3, V2, and V1)

The manufacturer shall use a temperature derated yield strength at the maximum rated temperature.

For validation grade V3, the supplier/manufacturer shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 and support stated product ratings and capabilities.

For calculation of validation grades V1 and V2:

- calculate PBR collapse pressure with partial engagement of the seal assembly according to API 5C3; and
- calculate fully engaged collapse pressure according to the Equation (4).

$$P_C = 2 \times S_Y \left[\frac{\left(\frac{D}{t}\right) - 1}{\left(\frac{D}{t}\right)^2} \right] \quad (4)$$

where

P_C is the pressure for yield strength collapse;

D is the specified minimum pipe outside diameter;

S_Y is the specified minimum yield strength;

t is the specified minimum pipe wall thickness.

For a seal assembly to be fully engaged, it shall meet one of the following criteria:

- a) a PBR having $D/t \leq 20$ and the distance from the bottom of the unsupported PBR to the lower seal unit on the seal assembly shall not exceed L/D of 2.
- b) a PBR having $D/t > 20$ and < 44 , and the distance from the bottom of the unsupported PBR to the lower seal unit on the seal assembly shall not exceed L/D of 1.

L is the specified unsupported length of applied pressure.

If desired, calculate partially engaged collapse pressure according to the supplier/manufacturer defined procedure and analysis. The procedure and analysis shall be validated by documented test results. The resulting output shall include details of engagement, methodology, and assumptions.

Calculate internal yield pressure according to the Equation (5)

$$P_i = 2 \times S_Y \left(\frac{t}{D} \right) \quad (5)$$

where

P_i is the internal pressure at yield for a thin tube;

D is the specified pipe outside diameter;

S_Y is the specified minimum yield strength;

t is the minimum pipe wall thickness. Calculations shall indicate conformance to the supplier/manufacture's documented criteria for that design and material.

6.6.13.3 Design Validation by Testing

For validation grade V3, the supplier/manufacture shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 and support stated product ratings and capabilities.

For validation grades V1 and V2, the supplier/manufacture shall document the TBR/PBR's dimension for each validation test performed. An MTR, which verifies the yield strength, shall be available for the tested TBR/PBR.

A V2 validated TBR/PBR without internal seal or internal connections is considered to meet the requirements of a V1 validated TBR/PBR.

A V2 or V1 validated TBR/PBR with seals or internal connections shall be validated according to the following requirements.

- Test the TBR/PBR in burst and collapse at the maximum rated temperature and pressure.
- For the burst test, test the entire TBR/PBR with a sealing element at each end of the TBR/PBR's sealing bore at maximum operating temperature.

Acceptance criteria for V2 is less than 1 % measured pressure drop during the pressure hold period of 15 minutes.

Acceptance criteria for V1 is zero bubbles of nitrogen observed over the hold period of 15 minutes.

For the collapse testing, the following tests are required:

- Test with a sealing element to provide a minimum of 3.98 m (10 ft) of unsupported length of the TBR/PBR. The maximum unsupported length of TBR/PBR shall be documented at maximum operating temperature.
- Test with the maximum engagement of the seal assembly at maximum operating temperature. The minimum unsupported length of TBR/PBR shall be documented.

Acceptance criteria for V2 is less than 1 % measured pressure drop during the pressure hold period of 15 minutes.

Acceptance criteria for V1 is zero bubbles of nitrogen observed over the hold period of 15 minutes.

Acceptance criteria: Post-test drifting of the full length shall be performed with a drift OD equal to or greater than the maximum diameter of the seal unit, less the sealing element with a minimum drift length at that diameter of 30.5 cm (12 in.).

Conduct post-test inspection according to supplier/manufacture procedure.

Prepare test report according to 6.6.5.

6.6.13.4 Limitations of Scaling for TBR/PBR Designs

A validation test conducted on a TBR/PBR design with a minimum length of 3.98 m (10 ft) validates all TBR/PBR designs of the same product family that are longer.

A validation test conducted on a TBR/PBR design may be applied to a TBR/PBR design of the same product family that is shorter than the validated design.

6.6.14 Seal Unit Design Validation Testing

6.6.14.1 General

Seal assemblies are used in conjunction with the TBR/PBR. This test only validates one seal unit.

NOTE The validation testing described in this section addresses static loading. For dynamic seal assembly validation testing, refer to API 19AC, Annex C.

Test data shall identify the leak rate, if deemed necessary, for the duration of the subject test. If no leakage occurred, this shall be clearly stated.

This specification includes three grades of design validation for seal assemblies:

- V3: Supplier/manufacturer-defined validation method.
- V2: Multiple stab-in at temperature with static liquid pressure test plus temperature cycling.
- V1: Multiple stab-in at temperature with static nitrogen pressure test plus temperature cycling.

6.6.14.2 Test Fixtures

Validation testing shall be conducted in a test fixture that is designed and manufactured to the ID tolerances and surface finishes of the production TBR/PBR.

The seal assembly mandrel shall be designed and manufactured to the OD tolerances, gland dimensions, and/or surface finishes of the production product.

The sealing unit shall be designed and manufactured to the nominal size, ID and OD tolerances, and material specification of the production product.

6.6.14.3 Validation Grade V3

The supplier/manufacturer shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 and support the stated product ratings and capabilities.

6.6.14.4 Design Validation Grades V1 and V2

The supplier/manufacturer shall adhere to the following test parameters in the order shown and to the criterion for conformance to this validation grade, which are listed in Table 7.

Table 7—Seal Unit Validation Procedure Grade V1 and V2

Step	Procedure and Acceptance Criteria	Data to be Documented
1	Conduct pre-test inspection according to supplier/manufacturer's procedures, which shall include dimension measurements.	Record inspection results
2	Heat fixture and seal unit to the max operating temperature minus one-half of the temperature cycle range ($\pm 10\%$).	Record temperature during test
3	Engage, disengage, engage, disengage, and engage (stab-in, stab-out, stab-in, stab-out, stab-in) the entire seal unit to the sealing bore (TBR/PBR).	Record linear movement
4	Increase the temperature to maximum rated temperature.	Record temperature during test
5	Perform pressure holds at or above the maximum rated differential pressures and a minimum of two pressure reversals. Relieve applied pressure then continue to next step. Acceptance criteria for V2: No more than 1 % reduction in the maximum rated differential pressure over the hold period. Acceptance criteria for V1: Zero bubbles of nitrogen observed over the hold period.	Pressuring during test Measured pressure loss for V2 Record acceptance or rejection
6	Reduce temperature by a minimum of the temperature cycle range value.	Record temperature during test
7	Perform a pressure hold and then a pressure reversal at or above the maximum rated differential pressures. Relieve applied pressure then continue to next step. Acceptance criteria for V2: No more than 1 % reduction in the maximum rated differential pressure over the hold period. Acceptance criteria for V1: Zero bubbles of nitrogen observed over the hold period.	Pressuring during test Measured pressure loss for V2 Record acceptance or rejection
8	Disengage entire seal unit from the sealing bore (stab-out).	—
9	Terminate test.	—
10	Conduct post-test inspection according to supplier/manufacturer's procedures. Prepare test report according to 6.6.5.	Dimensional inspection results Evidence of malfunction(s) or anomalies Test report

6.6.14.5 Limitations of Scaling of the Seal Assembly Design

Seal assemblies may be validated by scaling in accordance with 6.6.7.4.

6.6.15 Internal Thread Connections Design Validation

6.6.15.1 General

There are three grades of internal connection design validation: V1, V2, and V3. Each type, nominal size/ weight, and minimum material yield strength of the internal connection design shall be validated to the grade selected by the user/ purchaser. Internal connections shall be supplied to at least the design validation grade specified.

Internal connection validation test in accordance with this specification shall expose the connection to temperature, pressure (internal and/or external) and axial force (tension and/or compression), as defined in the functional specification.

NOTE The connection testing prescribed by this specification is a single combined loads test of the connection and does not include all of the connection testing variables as described in API 5C5.

6.6.15.2 Validation Grade V3

The supplier/manufacturer shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 and support the stated product ratings and capabilities.

6.6.15.3 Validation Grade V2

This design validation requires one of the following:

- a) V2 validation testing in accordance with 6.6.15.8;
- b) conformance to a minimum of API 5C5 CAL III;
- c) system testing (see 6.6.17.3) with the connection validated only to the conditions that were present during the testing.

6.6.15.4 Validation Grade V1

Requires one of the following:

- a) V1 validation testing in accordance with 6.6.15.8.
- b) conformance to a minimum of API 5C5 CAL III with additional nitrogen testing in accordance with 6.6.15.8, Table 8 Step 1 through Step 6.

Table 8—Internal Connection Validation Test Procedure Grades V2 and V1

Step	Procedure and Acceptance Criteria	Minimum Data to be Recorded
1	Record test data as specified.	Validation test number and grade Date Part number Serial number
2	Conduct test sample pre-test inspection according to supplier/manufacturer's procedures.	Dimensional inspection results MTR data
3	The connection shall be made up and installed in the test fixture using procedures and methods identified in referenced supplier/manufacturer procedures.	Make up torque Thread compounds
4	Increase the temperature to maximum rated temperature or higher, and run entire test, except temperature cycling, at or above the maximum rated temperature.	Temperature during test
5	Hold applied pressures or combinations of load and pressure for 15 minutes minimum. If no pressure loss is observed, it shall be documented in the test report. Acceptance criteria for V2: No more than 1 % reduction in the maximum rated differential pressure over the hold period. Acceptance criteria for V1: Zero bubbles of nitrogen observed over the hold period.	Measured pressure loss for V2

Table 8—Internal Connection Validation Test Procedure Grades V2 and V1 (Continued)

Step	Procedure and Acceptance Criteria	Minimum Data to be Recorded
6	<p>Apply pressure. Stabilize load, pressure, and temperature in accordance with supplier/manufacturer requirements.</p> <p>Test to a minimum of the pressure and load rating at the following intersection points of the rated performance envelope.</p> <p>Maximum external pressure.</p> <p>Maximum external with maximum compression.</p> <p>Maximum external with maximum tension.</p> <p>Remove all pressure and load before proceeding on to the next step.</p>	Applied pressure and load during test (if applicable)
7	<p>Test to a minimum of the pressure and load rating at all intersection points of the rated performance envelope. The minimum points that shall be tested from the operating performance envelope are listed below:</p> <p>Maximum internal pressure.</p> <p>Maximum tension.</p> <p>Maximum compression.</p> <p>Maximum internal with maximum tension.</p> <p>Maximum internal with maximum compression.</p> <p>Maximum external pressure.</p> <p>Remove all pressure and load before proceeding on to the next step.</p>	Applied pressure and load during test (if applicable)
8	Reduce temperature by a minimum of the temperature cycle range value.	Temperature during test
9	Repeat Steps 6 and 7.	Repeat Step 6 and 7
10	Conduct post-test inspection according to supplier/manufacturer's procedures.	<p>Dimensional inspection results</p> <p>Evidence of malfunction(s) or anomalies</p>

c) System testing (6.6.17.3) with the connection validated only to the conditions that were present during the testing.

NOTE Typically the thread supplier/manufacturer's validation testing does not include external nitrogen testing.

6.6.15.5 Internal Connection Rated Performance Envelope

The supplier/manufacturer shall state the performance ratings for the following: pressure, temperature, and axial loads, as applicable for the internal connection. Stated performance rating shall be shown in a performance envelope that illustrates the combined effects of internal and external pressure, temperature, and applied axial loads on the internal connection.

Rated performance envelopes shall meet the following criteria:

- a) The boundary of the envelope shall represent the supplier/manufacturer's maximum operational limits for the internal connection at maximum rated operating temperature.
- b) Tested data points shall be identified.
- c) The axial load shall be on the X axis.
- d) Pressure shall be on the Y axis.
- e) More than one graph may be displayed on the envelope if a legend is included for explanation.
- f) Axis and sign convention shall be oriented as shown in Figure 12.

An example envelope is illustrated in Figure 12.

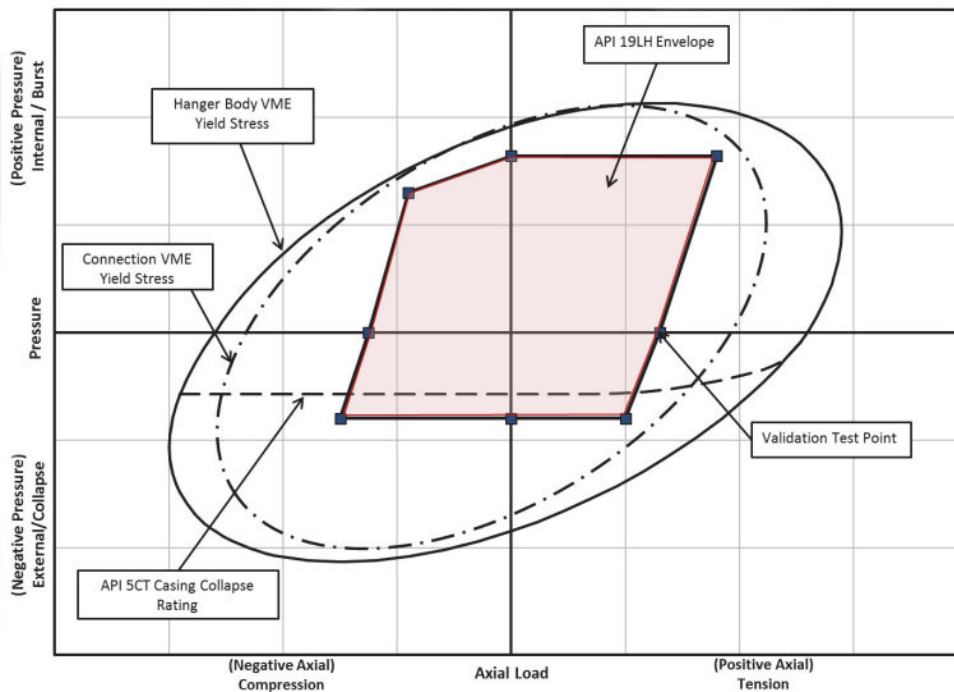


Figure 12—Internal Thread Rated Performance Envelope

6.6.15.6 Test Fixtures and Test Samples

Each test sample component shall:

- a) have an MTR that verifies the yield strength of the test sample is within the material specification;
- b) have measured and documented dimensions conforming to the design requirements;
- c) have a certificate of conformance or thread form dimensional verification stating that the thread form/type meets thread manufacturer requirements; and
- d) be made up in accordance with supplier/manufacture specifications (including application of thread compounds).

Validation testing shall be performed within a test fixture that houses the internal connection and provides functionality of applying temperature, internal pressure, external pressure, tension, and compression and any combination of these.

For the test fixture, a filler bar(s) is acceptable for the ID of the test sample and annulus space in the test fixture. Multiple connections may be tested in series.

6.6.15.7 Validation Grade V3

The supplier/manufacturer shall define the design validation method and acceptance criteria. The design validation shall conform to API Q1 and support the stated product ratings and capabilities.

6.6.15.8 Validation Grade V2 and V1 Test Procedure

Perform the test in accordance with Table 8. The steps shall be performed in the numbered order shown. Repair or redress of a connection during the testing phase requires the testing to restart at the beginning.

6.6.15.9 Limitations of Scaling of Internal Thread Connection

For validation grade V1, scaling is not permitted.

For validation grades other than V1:

- a) Scaling is not permitted for internal connections supplied by a third-party supplier except for material changes in which the specified minimum yield strength does not change.
- b) Successfully testing the lightest and heaviest weights of an internal connection design validates the connection design for all weights between the two tested. The tests shall be performed in accordance with documented procedures and acceptance criteria. The tested connections shall be of the same thread geometry and specified material yield strength.

6.6.16 Liner System Design Validation

6.6.16.1 General

As stated in 6.6.6, three grades of liner system design validation are specified for which the equipment shall be supplied:

- VS3: supplier/manufacturer-defined validation methods;
- VS2: liquid test plus axial loads plus pressure plus temperature cycling;
- VS1: nitrogen test plus axial loads plus pressure plus temperature cycling.

Liner systems qualified to higher grades of design validation may be considered qualified for the lower grades of design validation in accordance with Table 9.

Table 9—Liner System Design Validation Grade Hierarchy

Design Validation Grade	Grades Covered
VS1	VS1, VS2, VS3
VS2	VS2, VS3
VS3	VS3

There are two methods to obtain a validated liner system. The method used shall be identified by the supplier/manufacturer:

- combined individual product validation;
- system validation.

The supplier/manufacturer shall provide a performance envelope in accordance with 6.8 for either method.

An integrated liner system consisting of a single mandrel/tubular device that combines the functions of two or more products can be validated as a system, or the products can be validated individually. Those validation tests shall simulate the pressure and loading conditions that would be present if the entire integrated liner system were tested.

6.6.16.2 Liner System Validation by Assembly of Individually Validated Products

Individually validated products may be assembled to form a validated system, where the system grade and rating is determined by the lowest grade and rating of the individual products. Products validated individually may have different ratings. Individual products tested during prior system validation shall be considered individually validated to that system's grade and rating.

Supplier/manufacturer shall document any differences in the mechanisms, actuation, and load paths of the validated products used in the system and determine whether these differences are substantive differences when compared to the validation of individual products. When substantive differences are identified, the liner system shall be validated by testing in accordance with 6.6.17.3.

NOTE Ratings of validated products used during liner system validation may be limited by the performance properties of the test casing (size, weight, and grade).

6.6.16.3 Liner System Validation

The liner system validation shall test to a performance envelope and demonstrate individual product validation requirements of 6.6.8 through 6.6.15, as applicable.

Liner system validation testing shall include testing to the limits and order as defined in the applicable product testing; however, test steps can be combined to effectively achieve the defined testing criteria while minimizing testing repetition. Each of the rated performance envelope intersection points shall be tested. The blended liner system testing procedures, testing practices, and the documented testing results shall be performed by a qualified person, and the report of the results shall be approved by a second qualified person.

The supplier/manufacturer shall document the validation procedure and results, and shall have on file material specifications and drawings that show applicable dimensions and tolerances of components contained in the validated products and liner systems. Supplier/manufacturer shall perform pre- and post-test dimensional inspections and have material certificates for Type 1 components.

If a validated product within the liner system undergoes a substantive design change as described in 6.8.2, or any product is substituted by another product, liner system validation in accordance with this section is required.

6.7 Performance Envelope Requirements

6.7.1 General

For liner systems supplied to grades VS2, VS1, or when requested by the user/purchaser for VS3, a rated performance envelope shall be supplied for non-tied back and tied back liner system applications. These envelopes shall include graphic illustrations of the combined effects of pressure and axial loads on a liner system at maximum rated temperature.

An example envelope is illustrated in Figure 13. The area within the boundaries defines the rated performance envelope. The lines forming the boundary of the envelope are defined as the maximum operational limits for the system. Material mechanical properties over the temperature range shall be considered when determining performance ratings. Refer to Annex G for additional performance envelope examples.

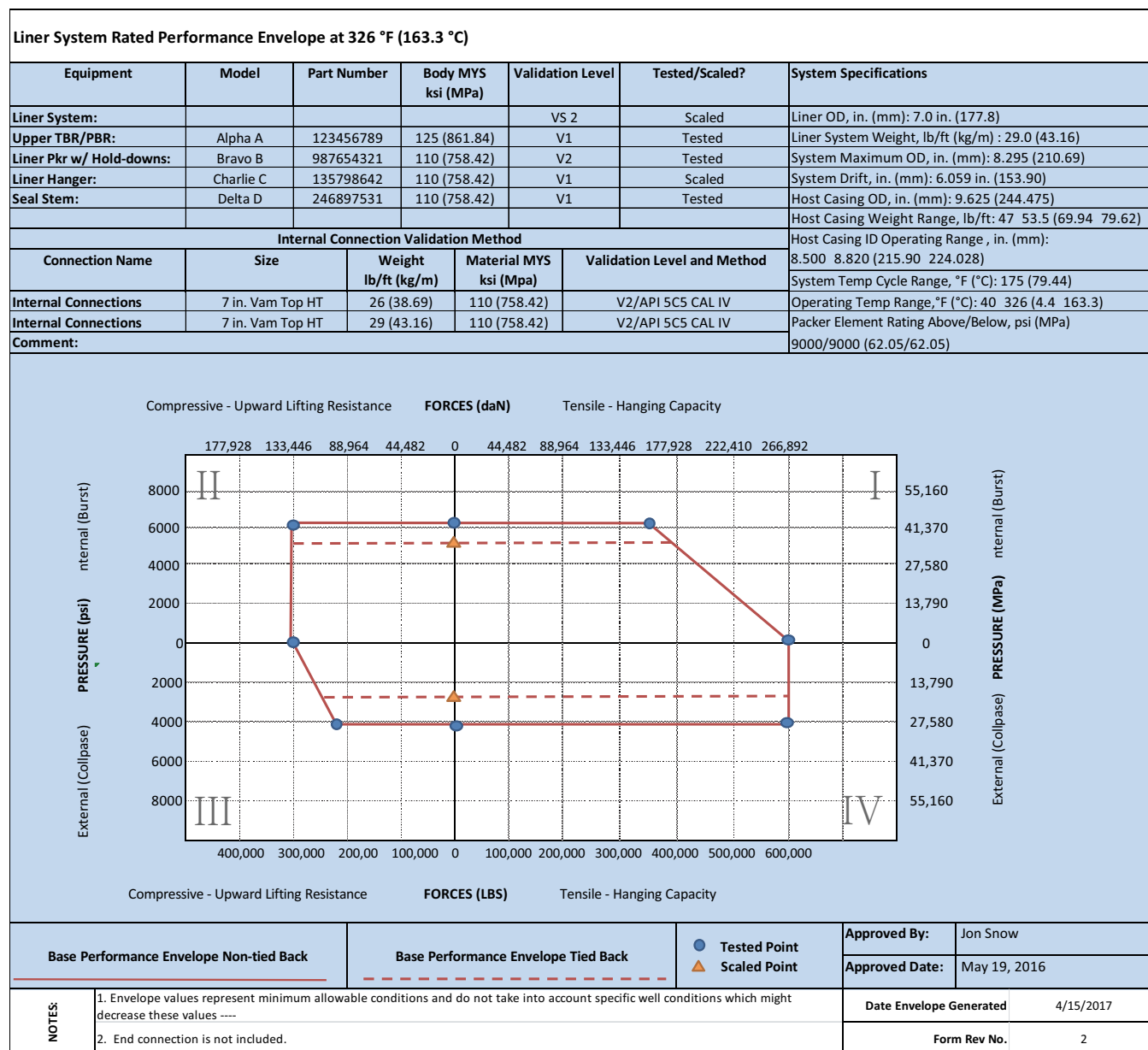


Figure 13—Performance Envelope Example

6.7.2 Performance Envelope Required Data

The supplier/manufacturer defines the performance envelope. The envelopes shall as a minimum include the criteria specified as follows:

- a) The boundary lines of the envelope shall represent the supplier/manufacturer's maximum ratings of compression (upward lifting resistance), tension (hanging capacity), internal pressure (burst), and external pressure (collapse) for the system design. Each of the illustrated ratings shall have defined increments.
- b) The system's load bearing and pressure-containing internal connections shall be stated with material minimum yield strength (MYS) and design validation method.
- c) The minimum and maximum host casing size, weight range, and ID operating range shall be specified with the envelope. The envelope shall be applicable over the specified ID range.
- d) Packer differential pressure rating above and below the element shall be stated but not shown on the figure created in a).
- e) Axis and rating increments shall be identified. The axial load shall be on the x-axis. The internal and external pressure shall be on the y-axis.
- f) Calculated ratings shall be differentiated from tested points of envelope data.
- g) The performance envelope shall be prepared and approved by separate qualified persons.
- h) Design validation grade.
- i) System maximum OD and minimum ID.
- j) Operating temperature range and temperature cycle range.
- k) Each product within the system shall be listed with the model, part number, body MYS, design validation grade, and whether the product design validation was scaled.
- l) System specifications shall be listed, including the liner OD and liner system weight.

6.7.3 VS2 and VS1 Envelopes

Envelopes shall be based upon full-scale testing and/or calculated data. The envelopes shall, as a minimum, include the criteria specified in 6.7.2 and indicate whether the envelope was obtained by testing a complete system or was obtained by evaluating and combining various product tests.

Users/purchasers shall consider applied loading of the system's applications when designing the wellbore configuration to ensure that operation of the product is within its rated capability.

NOTE Envelope values represent the maximum allowable conditions and do not consider well conditions, which might increase or decrease these values.

6.8 Design Changes

6.8.1 General

Design changes to existing validated product designs shall be documented and reviewed against the design verification and design validation to determine if the change is a substantive design change (see 3.1.72).

This evaluation shall include the following as a minimum:

- a) stress factors of the replaced or changed components or subassemblies relative to the base design;
- b) for components designed to plastically deform, strain factors of the replaced or changed components, or subassemblies relative to the base design;
- c) interchangeability of the changed components or subassemblies relative to the base design;
- d) functional or operational changes, including interaction with secondary and contingency tools.

Design changes shall conform to the design criteria and verification (see 6.3 and 6.4) that were applied to the base component or assembly and shall be compliant to requirements of 6.3.2 and 6.4.

Evaluation results and justifications as a nonsubstantive design change shall be approved by a qualified person (see 3.1.55) other than the person performing them, and records of the results shall become a portion of the design documentation (see 7.2.2).

6.8.2 Substantive Design Change

A product design that undergoes a substantive design change becomes a new product design requiring design verification (see 6.4) and design validation (see 6.6); however, scaling is allowed in accordance with 6.6.7 and the product-specific limitations on scaling.

Design validation for changes to components or subassemblies may be done by validation testing only the component or subassembly rather than the entire assembly. The test(s) shall simulate the test conditions that would be present if the entire assembly were tested. The supplier/manufacturer shall document the test results and analysis that demonstrate that the component or subassembly test simulates the required loading conditions.

7 Supplier/Manufacturer Requirements

7.1 General

Section 7 contains the detailed requirements necessary to verify that each product manufactured meets the requirements of the functional and technical specifications. These include requirements for:

- a) documentation and data control;
- b) product identification, materials;
- c) quality control;
- d) traceability;
- e) assembly verification;
- f) operational/functional testing; and
- g) shipping and storage.

Products and systems produced according to this specification shall be designed and manufactured under a QMS that conforms to a recognized quality management standard such as API Q1 or ISO/TS 29001.

7.2 Documentation and Data Control

7.2.1 General

The supplier/manufacturer shall establish and maintain documented procedures to control all documents and data that relate to the requirements of this specification. These documents and data shall be maintained to demonstrate conformance to specified requirements. All documents and data shall be legible and shall be stored and retained such that they are readily retrievable in facilities that provide a suitable environment to prevent damage or deterioration and to prevent loss. Documents and data may be in any form or type of media, such as hard copy or electronic media. All documents and data shall be available to and auditable by the user/purchaser.

All documentation and data associated with design verification, design validation, and design change justification shall be maintained for ten years after the date of last manufacture of the design.

Quality-control documentation includes all documents and data necessary to demonstrate conformance to 7.2.2 through 7.4.10. Quality-control documentation shall be retained by the supplier/manufacturer for a minimum of ten years from date of manufacture. These records shall be available to and auditable by the user/purchaser.

7.2.2 Design Documentation

Design documentation shall include:

- a) functional and technical specifications;
- b) design verification documents;
- c) design changes;
- d) one complete set of drawings, written specifications and standards;
- e) material type, yield strength, and connection identification for the actual end connection(s) provided with the product or system;
- f) operating manual;
- g) validation test files containing documentation to demonstrate compliance with 6.6.

7.2.3 Operating Manual

An operating manual shall be available prior to use for products or systems. Operating manuals shall contain the following information:

- a) manual reference number;
- b) storage recommendations;
- c) pre-installation inspection procedures;
- d) operational procedures and required running/setting tools;
- e) a representative drawing showing major dimensions (ODs, IDs, lengths);
- f) repair/redress requirements and limitations, if applicable as determined by supplier/manufacturer.

7.2.4 Data Sheets

7.2.4.1 General

Performance ratings included in data sheets shall be calculated at ambient conditions, unless stated otherwise on datasheet, and without the application of combined loading conditions.

7.2.4.2 Product Data Sheets

Product data sheets shall be available prior to transport, and shall contain the following information, as applicable:

- a) general information;
- b) name of supplier/manufacturer;
- c) manufacturer product number and description;
- d) operating manual reference number;
- e) product type;
- f) materials, by industry-accepted nomenclature;
- g) minimum ID of the product;
- h) drift diameter;
- i) gauge OD;
- j) overall length;
- k) liner and casing size, weight, and range;
- l) top and bottom connections, as applicable;
- m) design validation grade;
- n) performance characteristics, as applicable;
- o) operating temperature range;
- p) calculated performance ratings, including:
 - burst and collapse pressure ratings;
 - hanging capacity in unsupported casing;
 - tensile and compressive load ratings; and
 - torque rating;
- q) setting method, including minimum (maximum, as applicable) setting force/pressure;
- r) temperature cycle range for products validated for V1 and V2;

- s) maximum differential pressure rating;
- t) minimum bypass area using nominal casing ID;
- u) manufacturer-defined operational limitation;
- v) a report of the external flow test rating (if Annex C has been performed);
- w) a report of the bearing rating (if Annex F has been performed).

7.2.4.3 System Data Sheets

System data sheets shall be supplied to the user/purchaser, and shall contain the following information, as applicable:

- a) general information;
- b) name of supplier/manufacturer;
- c) manufacturer system description;
- d) operating manual reference number;
- e) system type;
- f) materials, by industry-accepted nomenclature;
- g) minimum ID of the system;
- h) drift diameter;
- i) gauge OD;
- j) overall length;
- k) liner and casing size, weight, and range;
- l) top and bottom connections, as applicable;
- m) design validation grade and method of validation;
- n) performance characteristics, as applicable;
- o) operating temperature range;
- p) calculated performance ratings, including:
 - burst and collapse pressure ratings;
 - hanging capacity in unsupported casing;
 - tensile and compressive load ratings;
 - torque rating;

- q) temperature cycle range for systems validated for VS1 and VS2;
- r) setting method, including minimum (maximum, as applicable) setting force/pressure;
- s) minimum bypass area using nominal casing ID;
- t) supplier/manufacturer-defined operational limitation;
- u) rated performance envelope in accordance with 6.7;
- v) a report of the external flow test rating (if Annex C has been performed);
- w) a report of the bearing rating (if Annex F has been performed).

7.3 Product Identification

Each product furnished to this specification shall be permanently physically marked according to the supplier/manufacturer's specifications. The supplier/manufacturer's specifications shall define the type, method of application, and location of the identifications. The following information shall be included:

- a) supplier/manufacturer name or logo;
- b) supplier/manufacturer's product description, such as size, weight, connection type, product name;
- c) supplier/manufacturer's product and/or part number;
- d) product(s) date of manufacture (month/year);
- e) design validation grade;
- f) product(s) quality grade and applicable traceability information in accordance with 7.4.6, including:
 - for quality grade QL1, a unique serial number is required;
 - for quality grade QL2, job-lot traceability (see 3.1.31) is required;
 - for quality grade QL3, supplier/manufacturer marking is required.

7.4 Quality Control

7.4.1 General

This specification provides three quality grades—QL1, QL2, and QL3, which are selected by the user/purchaser. Products and systems shall be supplied to at least the quality grade selected. Quality requirements shall be implemented to the documented requirements of supplier/manufacturer-defined practices and acceptance criteria. Quality requirements are detailed in 7.4.3 through 7.4.9 and are summarized in informative Table 10.

7.4.2 Personnel Qualifications

Personnel performing visual examinations shall have an annual eye examination, as applicable to the discipline to be performed, in accordance with ISO 9712 or ASNT SNT-TC-1A.

Personnel performing NDE evaluations and interpretations shall be qualified in accordance with ISO 9712 or ASNT SNT-TC-1A, to a minimum of Level II.

Table 10—Summary of Quality Requirements

	QL3	QL2	QL1
Metallic material (see 7.4.3.1 and 7.4.3.2)	certificate of compliance (COC) or MTR	COC or MTR	Verify independent MTR for metallic Type 1 components COC or MTR for
Nonmetallic material (see 7.4.3.1 and 7.4.3.3)	COC or MTR	COC or MTR	COC or MTR
Heat treatment (see 7.4.4)	Heat-treat traceability	Heat-treat traceability	Heat-treat traceability
Product traceability (see 7.4.6.2)	Supplier/manufacturer-defined	Job-lot traceable	Serialized traceability
Metallic component traceability (see 7.4.7.3)	Supplier/manufacturer-specified traceability	Job-lot traceable for Type 1 components Supplier/manufacturer-specified for	Serialized and heat-traceable to an MTR for Type 1 components Job-lot traceable for
Nonmetallic component traceability (see 7.4.7.3)	Supplier/manufacturer-specified traceability	Job-lot traceable	Job-lot traceable
General non-destructive examination (NDE) (see 7.4.7.1)	Supplier/manufacturer-defined	Visual inspection for	Visual inspection for
Metallic NDE (see 7.4.7.2)	Supplier/manufacturer-defined	Sampling plan in accordance with Annex H	100 % magnetic-particle or liquid-penetrant and ultrasonic inspection for Type 1 components
Nonmetallic NDE (see 7.4.7.3)	Sampling plan in accordance with Annex H	Sampling plan in accordance with Annex H	100 % of components
Component dimensions (see 7.4.7.4)	Supplier/manufacturer-defined	Sampling plan in accordance with Annex H	100 % for Type 1 components Sampling plan in accordance with Annex H for
Hardness (see 7.4.7.6)	Supplier/manufacturer-defined	Type 1 components are inspected in accordance with Annex H	are inspected in accordance with Annex H
Castings and forgings (see 7.4.7.7)	COC	COC	100 % magnetic-particle or liquid-penetrant and radiographic or ultrasonic inspection for Type 1 components
Coatings, plating, surface treatment (see 7.4.7.8)	Supplier/manufacturer-defined	Supplier/manufacturer-defined	Supplier/manufacturer-defined
Welding and brazing (see 7.4.7.9)	Visual inspection	Magnetic-particles or liquid-penetrant inspection sampling plan in accordance with Annex H	100 % magnetic-particles or liquid-penetrant inspection
Shear devices (see 7.4.8)	Shear verification	Shear verification	Shear verification
Assembly verification (see 7.4.9)	Supplier/manufacturer-defined	Low pressure test, functional test, ID drift	Low/high pressure test, functional test, ID drift, OD dimensional, torque documentation
QC documentation (see 7.2.1)	Supplier/manufacturer-retained	Supplier/manufacturer-retained	Supplier/manufacturer-retained

^a "Supplier/manufacturer-defined" indicates that there are no requirements listed in 7.4.3 through 7.4.9.

Personnel performing inspections for acceptance that are not defined by ISO 9712 or ANST SNT-TC-1A shall be qualified in accordance with the supplier/manufacture's documented requirements.

All NDE instructions shall be approved by a qualified NDE Level III examiner in accordance with ISO 9712 or ASNT SNT-TC-1A. Visual examination requirements do not require Level III approval.

7.4.3 Materials

7.4.3.1 General

Material, metallic or nonmetallic, used in the manufacture of components, shall meet one of the following requirements:

- a) COC to the supplier/manufacture stating that the material meets the supplier/manufacture's documented specifications; or
- b) MTR to the supplier/manufacture so that the supplier/manufacture can verify that the material meets the supplier/manufacture's documented specifications.

For quality grade QL1 metallic Type 1 components, the chemical/mechanical properties shall be verified independently of the original MTR testing facility. This verification may use chemical analysis determinations which are performed with positive material identification (PMI) equipment following the guidelines of API 578 or by chemical testing performed in accordance with the applicable ASTM test method. Mechanical properties may be determined by hardness tests or tensile tests conducted in accordance with 7.4.3.2. Each material's test results shall be approved by a qualified person as meeting the supplier/manufacture's specifications for the material.

7.4.3.2 Metals

To validate that the materials meet the supplier/manufacture's material specifications, the following methods shall be used where required by the material specification:

- Tensile testing shall be in accordance with ISO 6892-1 or ASTM E8 or ASTM A370 for the metallic materials used for traceable components.
- Elevated temperature tensile and modulus testing, where required by the supplier/manufacture material specification, shall be in accordance with ISO 6892-2 or ASTM E21 and ASTM E111.

Hardness testing shall be in accordance with the following:

- a) ISO 6506-1, ASTM E10, ISO 6508-1, or ASTM E18;
- b) ISO 6507-1 or ASTM E384 may be used if neither ISO 6506-1 nor ASTM E10 nor ISO 6508-1 nor ASTM E18 can be applied due to size, accessibility, or other limitations.

Charpy testing shall be in accordance with ASTM E23 or ASTM A370.

Hardness conversion to other measurement units shall be in accordance with ASTM E140 or ISO 18265, with the exceptions noted in ANSI/NACE MR0175. Where the supplier/manufacture has documented conversions approved by a qualified person for individual materials, they may be used in place of ASTM E140 or ISO 18265.

7.4.3.3 Nonmetals

This section does not cover electronic or electrical components.

The supplier/manufacturer shall purchase nonmetallic goods and services only from their approved suppliers. A documented procedure shall be implemented to ensure that each nonmetallic supplier's products conform to the supplier/manufacturer's material specification on a repeatable basis.

NOTE ISO 23936-1 and ISO 23936-2 contain provisions on qualification of nonmetallic sealing material.

Each nonmetallic material supplier shall be evaluated annually to ensure that the applicable controls of all materials, compounds, and component processes effectively ensure consistent conformance to the material and technical specifications. These evaluations shall be performed by qualified persons in the applicable technology.

Supplier evaluation records shall identify the materials/components that are approved to be provided by each specific supplier. Supplier documented evaluation records shall include the necessary corrective measures and verification of their implementation.

The supplier/manufacturer's documented specifications for nonmetallic compounds shall include handling, storage, and labeling requirements and define the quality control limits of characteristics necessary for the performance of the material. Mechanical properties required by the material specification shall be validated by test conducted on a material sample produced from the same batch of material. Mechanical property test procedures shall be as follows:

a) Tensile, elongation, modulus:

- O-rings in accordance with ASTM D1414 or ASTM D412;
- other elastomers in accordance with ASTM D412 (alternative ISO or ASTM methods may be used, where applicable);
- non-elastomers in accordance with ASTM D638 or ASTM D1708;

NOTE For the purposes of these provisions, ISO 527-1 is equivalent to ASTM D638.

b) Compression set (homogeneous elastomeric materials only):

- O-rings in accordance with ASTM D1414 or ASTM D395;
- all others in accordance with ASTM D395;

c) Durometer hardness:

- O-rings in accordance with ASTM D1415 or ASTM D2240;
- other elastomers in accordance with ASTM D2240, Shore A;
- thermoplastics and other materials in accordance with ASTM D785, Shore D.

Electrical and electronic components shall be covered by documented requirements of the supplier/manufacturer, which include performance requirements and acceptance criteria.

7.4.3.4 Castings and Forgings

The production of castings and forgings shall conform to the same practices and controls as were applied to the successfully validation-tested component and the first article produced.

NOTE API 20A, API 20B, and API 20C contain information on castings, open die forgings, and closed die forgings, respectively.

7.4.4 Heat Treatment

The supplier/manufacturer shall have documented procedures for each material, material condition, and process that includes acceptance criteria for the heat treatment of components. Heat treatment of components or raw materials shall meet the following requirements:

- a) Heat treatment shall be performed with controlled and monitored heat-treating equipment that has been calibrated and surveyed in conformance with a referenced national or international standard such as AMS 2750, API 6A, or API 20H. Calibration intervals shall not exceed twelve calendar months.
- b) Heat treatment shall comply with the supplier/manufacturer's documented specifications and acceptance criteria. This shall be documented and approved by a qualified person.
- c) Heat treated material shall be traceable to the documented heat treatment process(es) applied to that component.

7.4.5 Stress Relief

Stress relief is heat treatment used to release integral material stresses caused by manufacturing. Stress relief may be performed without a furnace (e.g. a localized stress relief of a weld), to a documented procedure, and with the temperature measurement and recording instruments calibrated to 7.5. A hardness test shall be performed on each stress relieved area, and the results shall be evaluated by a qualified person as within the documented acceptance criteria.

Each welded component shall be stress relieved as specified in the supplier/manufacturer's written specifications or in accordance with ASME BPVC, Section VIII, Division 1, UW-40. In addition, carbon and low-alloy steel weldments on sour service equipment shall be stress relieved in accordance with ANSI/NACE MR0175.

7.4.6 Traceability

7.4.6.1 General

Traceability shall be in accordance with the manufacturer's documented procedures. The supplier/manufacturer shall determine what components will be classified as Type 1, in accordance with documented procedures.

7.4.6.2 Product Traceability

QL1 products shall be uniquely serialized.

QL2 products shall have job-lot traceability.

QL3 products shall have supplier/manufacturer-defined traceability.

7.4.6.3 Component Traceability

Component traceability shall meet the following requirements:

- a) For quality grade QL3, components shall have supplier/manufacturer-specified traceability.
- b) For quality grade QL2, metallic Type 1 components shall be job-lot traceable, and metallic shall have supplier/manufacturer-specified traceability.
- c) For quality grade QL1, metallic Type 1 components shall be serialized and be heat-traceable to an MTR. For quality grade QL1, and all castings shall have job-lot traceability.
- d) Nonmetallic components shall be job-lot traceable for quality grades QL1 and QL2.

- e) Common hardware (see 3.4) does not require traceability.
- f) For all quality grades, shear devices shall be job-lot traceable with one heat per job-lot.

7.4.7 NDE Inspections

7.4.7.1 General

NDE of components shall meet the following requirements:

- a) NDE shall be performed in accordance with the supplier/manufacturer's documented requirements and acceptance criteria.
- b) for quality grade QL1 and QL2 shall be visually inspected in accordance with the supplier/manufacturer's documented specifications.

7.4.7.2 Metallic

NDE of metallic components shall meet the following requirements, as applicable.

- a) NDE for metallic components shall be magnetic-particle inspection or liquid-penetrant inspection:
 - magnetic-particle inspection, see 7.4.7.11;
 - liquid-penetrant inspection, see 7.4.7.12.
- b) Type 1 components for quality grade QL2 shall be NDE-inspected in a sampling plan, in accordance with Annex H.
- c) Type 1 components for quality grade QL1 shall be 100 % NDE-inspected using liquid-penetrant or magnetic particles, as defined in 7.4.7.11 or 7.4.7.12.
- d) Raw material for Type 1 components for quality grade QL1 shall be 100 % inspected using ultrasonic inspection, as defined in 7.4.7.10.

7.4.7.3 Nonmetallic

NDE of nonmetallic components shall meet the following requirements:

- a) NDE for nonmetallic components shall be visual inspection in accordance with supplier/manufacturer's documented specifications. Visual inspection of O-rings shall be in accordance with ISO 3601-3 or equivalent.
- b) Components for quality grade QL2 shall use a sampling plan in accordance with Annex H.
- c) Components for quality grade QL1 shall be 100 % NDE-inspected.

7.4.7.4 Component Dimensional Inspections

Components, except common hardware, shall be dimensionally inspected according the supplier/manufacturer's procedures by a qualified person(s) to ensure proper function and compliance with the design criteria and specifications. Inspection shall be performed during or after the manufacture of the components, but prior to assembly, unless assembly is required for proper measurement.

- a) Type 1 and for quality grade QL2 shall be inspected in accordance with the sampling plan in Annex H.

- b) Type 1 components for quality grade QL1 shall be 100 % dimensionally inspected and documented.
- c) for quality grade QL1 shall be inspected in accordance with the sampling plan in Annex H.

Dimensional tolerances of O-rings shall be in accordance with supplier/manufacturer's specifications.

Sealing elements and nonmetallic components other than O-rings shall meet dimensional tolerances of the supplier/manufacturer's documented specifications and acceptance criteria.

7.4.7.5 Thread Inspection

All API tapered-thread tolerances, inspection requirements, gauging, gauging practice, gauge calibration, and gauge certification shall be in accordance with API 5B or API 7-2, as applicable.

All other thread tolerances, inspection requirements, gauging, gauging practice, gauge calibration, and gauge certification shall conform to the specified thread design owner's written specifications.

7.4.7.6 Hardness Inspection of Components

Hardness inspection shall be performed in accordance with ISO 6506, Parts 1 through 4 (Brinell) or ISO 6508, Parts 1 through 3 (Rockwell). ISO 6507, Parts 1 through 4 (Vickers) may be used when ISO 6506-1 or 6508-1 cannot be applied due to size, accessibility, or other limitation.

NOTE For the purposes of this standard, ASTM E10 is equivalent to ISO 6506, ASTM E18 is equivalent to ISO 6508, and ASTM E92 is equivalent to ISO 6507.

Slips shall be hardness tested in accordance with supplier/manufacturer approved procedures and acceptance criteria.

Type 1 components for quality grade QL1 shall be 100 % hardness inspected.

for quality grade QL1 shall be hardness inspected in accordance with a sampling plan (see Annex H).

Type 1 components for quality grade QL2 shall be hardness inspected in accordance with a sampling plan (see Annex H).

The durometer hardness of O-rings or other elastomeric seals shall be determined in accordance with a national or international standard, such as ASTM D2240 or ASTM D1415. A minimum of one seal manufactured from each batch shall be hardness tested.

7.4.7.7 Castings, Forgings, and Wrought Products

The casting subcontractor or supplier shall provide a COC to the supplier/manufacturer stating that the casting meets the supplier/manufacturer's documented specifications.

Type 1 castings, forgings, and wrought components for quality grade QL1 shall be magnetic particle or liquid-penetrant inspected (see 7.4.7.11 and 7.4.7.12) for surface defects and shall be volumetrically inspected by ultrasonic techniques (see 7.4.7.10) to verify conformance with the supplier/manufacturer's specifications.

7.4.7.8 Coatings, Platings, and Surface Treatments

Coatings, platings, and surface treatments shall be performed in accordance with supplier/manufacturer instructions and acceptance criteria, including thickness, and approved by a qualified person.

Instructions shall include, as a minimum, requirements for the following:

- a) surface cleanliness;
- b) surface preparation;
- c) application process;
- d) wet and dry film thickness;
- e) inspection requirements;
- f) personnel qualification;
- g) environmental conditions.

7.4.7.9 Welding and Brazing

NDE of welds shall meet the following requirements:

- a) Welds shall be visually inspected in accordance with the requirements of a specification or national standard, such as the ASME Boiler and Pressure Vessel Code, Section V, Article 9, with acceptance criteria in accordance with ASME BPVC Section IX articles QW-194 and QW-195, 2.2.
- b) Welds for quality grade QL2 shall be NDE-inspected using liquid-penetrant or magnetic particle in accordance with a sampling plan (see Annex H).
- c) Welds for quality grade QL1 shall be 100 % NDE-inspected using liquid-penetrant or magnetic particle (see 7.4.7.11 and 7.4.7.12).
- d) When required by the supplier/manufacturer's documented specification, each welded component shall be stress-relieved. All final inspections shall be performed after all thermal operations are completed.

7.4.7.10 Ultrasonic Inspection of Components

Ultrasonic inspection of components shall be in accordance with ASTM E428 and ASTM A388, or ASTM E213, as applicable.

Any of the following product defects shall be basis for rejection:

- a) Back reflection technique—indications greater than 50 % of the referenced back reflection accompanied by a complete loss of back reflection;
- b) Flat bottom hole technique—indications equal to or larger than the indications observed from the calibration flat bottom hole;
- c) Angle beam technique—amplitude of the discontinuities exceeding those of the reference notch.

7.4.7.11 Magnetic Particle Inspection of Components

Wet magnetic particle examination shall be in accordance with ISO 10893-5 or ASTM E709.

Indications shall be described as one of the following:

- a) Relevant indication—only those indications with major dimensions greater than 1.6 mm (1/16 in.) shall be considered relevant, whereas inherent indications not associated with a surface rupture (i.e. magnetic permeability variations, nonmetallic stringers, etc.) shall be considered nonrelevant;
- b) Linear indication—any indication in which the length is equal to or greater than three times its width;
- c) Rounded indication—any indication which is circular or elliptical in which the length is less than three times its width;
- d) Acceptance criteria:
 - any relevant indication greater than or equal to 4.8 mm (3/16 in.) shall be considered unacceptable;
 - no relevant linear indications shall be allowed for weldments;
 - no more than 10 relevant indications shall be present in any 39 cm² (6 in.²) area;
 - four or more rounded relevant indications in a line separated by less than 1.6 mm (1/16 in.) shall be considered unacceptable.

7.4.7.12 Liquid-penetrant Inspection of Components

Liquid-penetrant inspection shall be in accordance with ASTM E165 and meet the following acceptance criteria:

- a) no relevant linear indications;
- b) no relevant rounded indications greater than 5 mm (3/16 in.);
- c) no more than four or more relevant rounded indications in a line separated by 1.5 mm (1/16 in.) or less (edge-to-edge).

7.4.8 Shear Device Verification

At least one shear device per heat-lot shall be sheared in accordance with the supplier/manufacturer's documented procedure to verify that the shear value meets the documented specification.

7.4.9 Assembly Verification

Assembly verification shall meet the following requirements:

- a) For quality grade QL3, assembly verification shall be conducted in accordance with supplier/manufacturer-defined specification.
- b) For quality grades QL1 and QL2, an internal test shall be performed on each product that contains a potential leak path between the ID and the OD of the product by applying internal pressure to a minimum of 0.35 MPa (50 psi), using either liquid with corrosion inhibitors or nitrogen as the test medium. Test duration shall be a minimum of 5 minutes after stabilization. Acceptance criteria shall be defined by the supplier/manufacturer's documented procedures. Test data shall be recorded, dated, and signed by the qualified person performing the tests. Connections that are not made up as a part of product assembly are excluded from this requirement.

For quality grade QL1, an additional internal test shall be conducted to a minimum of 60 % of rated internal pressure or 34.50 MPa (5000 psi), whichever is less. Test duration shall be a minimum of 15 minutes after stabilization.

- c) For quality grades QL1 and QL2, a suppliers/manufacture-defined functional test shall be completed, as applicable.
- d) For quality grades QL1 and QL2, ID drift each product in accordance with the supplier/manufacture's documented specifications. Drift diameter shall match the rated drift diameter of the product. Drift dimensions shall meet the requirements specified in API 5CT, where applicable.
- e) For quality grade QL1, the OD shall be inspected according to the supplier/manufacture's documented specifications. OD dimensional inspection shall verify that the entire OD of the assembly is less than or equal to the maximum specified OD.
- f) For quality grade QL1, actual torque values for all connections that require torque value shall be recorded and verified to be within the supplier/manufacture's documented specifications. End connections are specifically excluded from this requirement.

7.4.10 Manufacturing Nonconformance

The supplier/manufacture shall establish and maintain documented procedures to ensure that an assembly or component that does not conform to specified requirements is prevented from unintended use or installation. This control shall provide for identification, documentation, evaluation, segregation (when applicable), and disposition of nonconforming assemblies or components.

The responsibility for review and authority for the disposition of nonconforming assemblies or components shall be defined by the supplier/manufacture. Nonconforming assemblies or components may be one of the following:

- a) accepted with or without repair with technical justification;
- b) reworked to meet the specified requirements; or
- c) rejected or scrapped.

Repaired and/or reworked assemblies or components shall be inspected in accordance with the requirements of the appropriate quality grade and the documented specifications of the supplier/manufacture.

7.5 Calibration

Inspection, measuring, and testing equipment used for acceptance shall be used within its calibrated range and shall be identified, controlled, calibrated, and adjusted at specific intervals in accordance with the manufacturer's procedures that are based on an internationally recognized standard, such as ISO/IEC 17025 or ANSI/NCSL Z540-3. Technologies for inspections with verifiable accuracies equal to or better than those listed in this international standard may be applied with appropriate documentation and when approved by a qualified person(s). Calibration intervals for measuring and testing equipment shall be established based on repeatability and degree of usage.

Calibration intervals shall be a maximum of three months until a recorded calibration history can be established. Intervals may then be lengthened or shortened based on documented repeatability, amount of usage, and calibration history. The calibration interval cannot be increased by more than twice the previous interval, which is not to exceed one year. Calibration standards used to calibrate measuring equipment shall be checked and approved at least once every three years by an independent outside agency with traceability to the applicable recognized national or international standards agency.

8 Return to Manufacturing for Rework

Rework of liner hanger products shall be conducted according to procedures established by the supplier/manufacturer and shall return the product to a condition meeting all requirements stated in this specification or the edition of this specification in effect at the time of the original manufacture.

9 Shipping, Handling, and Storage

Liner hanger products shall be handled and stored according to the documented specifications of the supplier/manufacturer in order to prevent deterioration.

Liner hanger products shall be packaged for transport according to the documented specifications of the supplier/manufacturer in order to prevent damage to the equipment from normal handling and contamination. All material provided as protection for transport shall be clearly identified for removal prior to equipment use.

Recommendations for storage shall be identified in the product operating manual.

Annex A (informative)

API Monogram Annex **Use of the API Monogram by Licensees**

A.1 Scope

The API Monogram® is a registered certification mark owned by the American Petroleum Institute (API) and authorized for licensing by the API Board of Directors. Through the API Monogram Program, API licenses product manufacturers to apply the API Monogram to new products which comply with product specifications and have been manufactured under a quality management system that meets the requirements of API Spec Q1. API maintains a complete, searchable list of all Monogram licensees on the API Composite List website (<http://compositelist.api.org>).

The application of the API Monogram and license number on products constitutes a representation and warranty by the licensee to API and to purchasers of the products that, as of the date indicated, the products were manufactured under a quality management system conforming to the requirements of API Spec Q1 and that the product conforms in every detail with the applicable standard(s) or product specification(s). API Monogram Program licenses are issued only after on-site audits have verified that an organization has implemented and continually maintained a quality management system that meets the requirements of API Spec Q1 and that the resulting products satisfy the requirements of the applicable API product specification(s) and/or standard(s). Although any manufacturer may claim that its products meet API product requirements without monogramming them, only manufacturers with a license from API can apply the API Monogram to their products.

Together with the requirements of the API Monogram license agreement, this annex establishes the requirements for those organizations who wish to voluntarily obtain an API license to provide API monogrammed products that satisfy the requirements of the applicable API product specification(s) and/or standard(s) and API Monogram Program requirements.

For information on becoming an API Monogram Licensee, please contact API, Certification Programs, 200 Massachusetts Avenue, NW, Washington, DC 20001 at Certification@api.org.

A.2 Normative References

For Licensees under the Monogram Program, the latest version of this document shall be used. The requirements identified therein are mandatory.

A.3 Terms and Definitions

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

A.3.1

API monogramable product

Product that has been newly manufactured by an API Licensee using a fully implemented API Spec Q1 compliant quality management system and that meets all the API-specified requirements of the applicable API product specification(s) and/or standard(s).

A.3.2

API product specification

Prescribed set of rules, conditions, or requirements attributed to a specified product that address the definition of terms; classification of components; delineation of procedures; specified dimensions; manufacturing criteria; material requirements, performance testing, design of activities; and the measurement of quality and quantity with respect to materials; products, processes, services, and/or practices.

A.3.3**API-specified requirements**

Requirements, including performance and Licensee-specified requirements, set forth in API Spec Q1 and the applicable API product specification(s) and/or standard(s).

NOTE Licensee-specified requirements include those activities necessary to satisfy API-specified requirements.

A.3.4**design package**

Records and documents required to provide evidence that the applicable product has been designed in accordance with API Spec Q1 and the requirements of the applicable product specification(s) and/or standard(s).

A.3.5**licensee**

Organization that has successfully completed the application and audit process, and has been issued a license by API to use the API Monogram Mark.

A.4 Quality Management System Requirements

An organization applying the API Monogram to products shall develop, maintain, and operate at all times a quality management system conforming to API Specification Q1.

A.5 Control of the Application and Removal of the API Monogram

Each licensee shall control the application and removal of the API Monogram in accordance with the following:

- a) Products that do not conform to API-specified requirements shall not bear the API Monogram.
- b) Each licensee shall develop and maintain an API Monogram marking procedure that documents the marking/monogramming requirements specified by this annex and any applicable API product specification(s) and/or standard(s). The marking procedure shall:
 - 1) define the authority responsible for application and removal of the API Monogram and license number;
 - 2) define the method(s) used to apply the Monogram and license number;
 - 3) identify the location on the product where the API Monogram and license number are to be applied;
 - 4) require the application of the date of manufacture of the product in conjunction with the use of the API Monogram and license number;
 - 5) require that the date of manufacture, at a minimum, be two digits representing the month and two digits representing the year (e.g. 05-12 for May 2012) unless otherwise stipulated in the applicable API product specification(s) or standard(s); and
 - 6) define the application of all other required API product specification(s) and/or standard(s) marking requirements.
- c) Only an API licensee shall apply the API Monogram and its designated license number to API monogramable products.
- d) The API Monogram and license number, when issued, are site-specific and subsequently the API Monogram shall only be applied at that site specific licensed facility location.

- e) The API Monogram may be applied at any time appropriate during the production process but shall be removed in accordance with the licensee's API Monogram marking procedure if the product is subsequently found to be out of conformance with any of the requirements of the applicable API product specification(s) and/or standard(s) and API Monogram Program.

For certain manufacturing processes or types of products, alternative API Monogram marking procedures may be acceptable. Requirements for alternative API Monogram marking are detailed in the API Alternative Marking Agreement (AMA), which is available on the API Monogram Program website at: https://www.api.org/~media/Files/Certification/Monogram-APIQR/0_API-Monogram-APIQR/Resources/API-Monogram-Alt-Marking-Agreement_Rev-8_FM-011_Modified-20180601.pdf

A.6 Design Package Requirements

Each licensee and/or applicant for licensing shall maintain a current design package for all of the applicable products that fall under the scope of each Monogram license. The design package information shall provide objective evidence that the product design meets the requirements of the applicable and most current API product specification(s) and/or standard(s). The design package(s) shall be made available during API audits of the facility.

In specific instances, the exclusion of design activities is allowed under the Monogram Program, as detailed in Advisory # 6, available on the API Monogram Program website at <https://www.api.org/products-and-services/api-monogram-and-apiqr/advisories-updates>.

A.7 Manufacturing Capability

The API Monogram Program is designed to identify facilities that have demonstrated the ability to manufacture equipment that conforms to API specifications and/or standards. API may refuse initial licensing or suspend current licensing based on a facility's level of manufacturing capability. If API determines that additional review is warranted, API may perform additional audits (at the organization's expense) of any primary subcontractors to ensure their compliance with applicable specifications.

Facilities with capabilities that are limited to the processes or activities defined below do not meet the manufacturing capability requirements to produce new products, and therefore, shall not be licensed or be the basis for licensing under the API Monogram Program:

- Capabilities that are limited to performing final inspection and testing of the product, except for testing agencies as specified in API Spec 14A and/or API Spec 6AV
- Buying, selling and/or distributing finished products and materials;
- Design and development activities;
- Tearing-down and/or re-assembling of products/components; and,
- Repairing or remanufacturing of existing, used, worn or damaged products.

In all instances where requirements for manufacturing or manufacturing facilities are explicitly identified within the API product specification, those requirements shall take precedence over this advisory.

A.8 Product Marking Requirements

A.8.1 General

These marking requirements shall apply only to those API Licensees wishing to mark applicable products in conjunction with the requirements of the API Monogram Program.

A.8.2 Product Specification Identification

Manufacturers shall mark products as specified by the applicable API specifications or standards. Marking shall include reference to the applicable API specification and/or standard. Unless otherwise specified, reference to the API specifications and/or standards shall be, as a minimum, “API [Document Number]” (e.g. API 6A, or API 600). Unless otherwise specified, when space allows, the marking may include use of “Spec” or “Std,” as applicable (e.g. API Spec 6A or API Std 600).

A.8.3 Units

Products shall be marked with units as specified in the API specification and/or standard. If not specified, equipment shall be marked with U.S. customary (USC) units. Use of dual units [USC units and metric (SI) units] may be acceptable, if such units are allowed by the applicable product specification and/or standard.

A.8.4 Nameplates

Nameplates, when applicable, shall be made of a corrosion-resistant material unless otherwise specified by the API specification and/or standard. Nameplate shall be located as specified by the API specification and/or standard. If the location is not specified, then the licensee shall develop and maintain a procedure detailing the location to which the nameplate shall be applied. Nameplates may be attached at any time during the manufacturing process.

The API Monogram and license number shall be marked on the nameplate, in addition to the other product marking requirements specified by the applicable product specification and/or standard.

A.8.5 License Number

The API Monogram license number shall not be used unless it is marked in conjunction with the API Monogram. The license number shall be used in close proximity to the API Monogram.

A.9 API Monogram Program: Nonconformance Reporting

API solicits information on products that are found to be nonconforming with API-specified requirements, as well as field failures (or malfunctions), which are judged to be caused by either specification and/or standard deficiencies or nonconformities against API-specified requirements. Customers are requested to report to API all problems with API monogrammed products. A nonconformance may be reported using the API Nonconformance Reporting System available at <http://ncr.api.org/ncr.aspx>.

Annex B

(informative)

Functional Requirements Example Check List

B.1 Well Parameters

The following is a list of well parameters:

- Company name;
- Field name;
- Lease/block;
- Well name/number;
- City/county;
- State/province/country;
- Company contact (office/rig);
- Rig (contractor/name/type);
- Well type (producer/injector/oil/gas/steam/disposal/etc.);
- Liner type (drilling/production);
- Wellbore schematic (depths/hole sizes/casing details/etc.);
- Restrictions (wellhead/previous liners/etc.);
- Liner (specifications/connections/shoe depth/top depth/etc.);
- Casing (specifications/connections/shoe depth/top depth/etc.);
- Well fluid (type/density/etc.);
- Directional (type profile/dogleg severity/maximum inclination);
- Combined loading constraints (tension/compression/burst/collapse/torque);
- Differential pressure (maximum/minimum at top of liner [TOL]);
- Temperature (bottom hole/TOL/etc.)
- Any other relevant well parameters.

B.2 Operational Parameters

The following is a list of operational parameters:

- Liner hanger type (conventional/expandable/hydraulic/mechanical/etc.);
- Equipment requirements (primary/back-up, second-trip packer, etc.);
- Dimensional (maximum OD/minimum ID/bypass area/maximum flow rate/etc.);
- Metallurgy (carbon steel/corrosion-resistant alloys/etc.);
- Sealing material environmental compatibility;
- Running tool (dimensions/specifications/operating pressures/etc.);
- Rotational capability (drill-in/reaming/while cementing/etc.);
- Running string (specifications/connections/lengths/etc.);
- Cement company;
- Cementing objective (shoe/zonal isolation/etc.);
- Cement head (type/company);
- Plugs and darts (single/dual/etc.);
- Shoe track (shoe/float collar/landing collar/auto-fill/etc.);
- Surge reduction (diverter/flow-back tools/providers/etc.);
- Integral liner packer;
- Polished-bore receptacle (length/configuration/dressing mills/etc.);
- Tie-back (objective/casing/cement/seal assembly/space-out/etc.);
- Centralization (type/supplier/etc.);
- Running constraints (maximum set-down/torque limits/emergency release/etc.);
- Setting constraints (setting loads/maximum pressure/contingency set/etc.);
- Post-installation constraints (burst/collapse/hanging capacity/differential/etc.);
- Any other relevant operational parameters.

Annex C **(informative)**

External Flow Testing

C.1 Scope

This annex defines the requirements for external flow testing of liner hanger equipment.

C.2 General

C.2.1 Testing Requirements

Testing shall be performed within the limits specified with liquid, to defined acceptance criteria, with suitable documentation, and approval of the results. The supplier/manufacturer stated external flow rating(s) shall be within the measurements recorded during this testing. The test results and ratings shall be included in the product design documentation.

C.2.2 Personnel

Preparation, testing, and approval of results shall be conducted by qualified personnel.

C.2.3 Measuring and Monitoring Equipment

Measuring and monitoring equipment used during the testing shall be calibrated to 7.5. All pressures and flow rates are defined as gauge unless otherwise specified and shall be recorded on time-based equipment.

C.2.4 Procedures

The supplier/manufacturer shall develop procedures for conducting the external flow tests, which shall be documented and included in the final report of the results. The procedures shall include acceptance criteria.

C.2.5 Test Fixture

The liner hanger equipment shall be installed in a section of casing/fixture within the weight range of the product's specification. The actual ID of the test casing shall be recorded in the test report. The end of the liner hanger equipment shall be closed in order to direct all flow entering the fixture to flow around the outside of the product.

See Figure C.1 for an illustration of an example test fixture.

C.3 Test Processes

Conduct the external flow testing according to the following steps:

- 1) Place the liner hanger equipment under test into the test fixture;
- 2) Secure the test fixture, and attach the flow lines to each end of the fixture;
- 3) Direct the water through the fixture starting at 79 l/m (0.5 bpm) or 50 % of the defined maximum flow rate, whichever is greater, while monitoring pressure drop across the defined location for a minimum of 5 minutes;

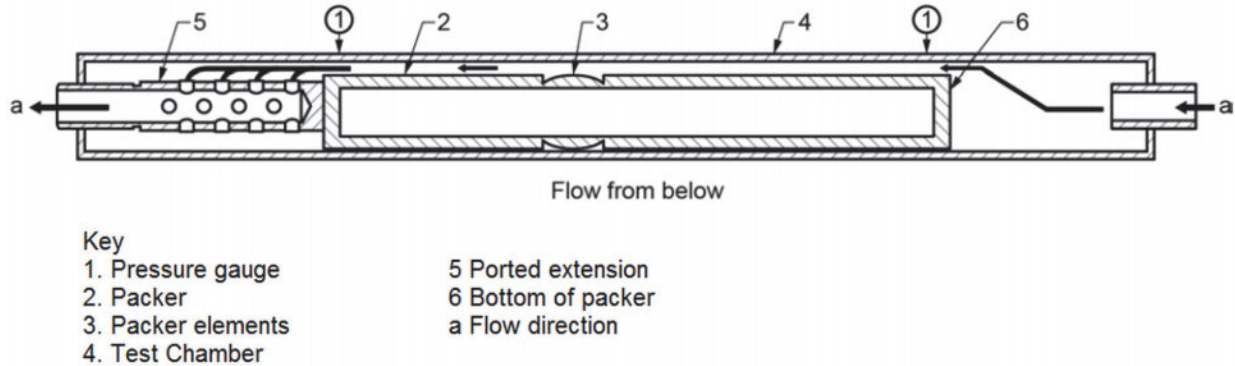


Figure C.1—Illustration of an Example Test Fixture for Flow Testing

- 4) Increase the flow rate by 79 l/m (0.5 bpm) every 5 minutes until the external flow rate meets or exceeds to the supplier/manufacture-defined maximum external flow rate.
- 5) Pump the water through the test fixture for a minimum of two hours at the defined maximum external flow rate.
- 6) The test is concluded when the pressure or flow rate meets the supplier's/manufacture's stated acceptance criteria or when the maximum flow rate is achieved.

C.4 Report

A test report shall be prepared in conformance with 6.6.5.

C.5 Scaling of External Flow Testing

The supplier/manufacture shall not use scaling to validate products with higher velocity ratings than the validated product.

Packing elements and anti-extrusion components of the scaled product design shall be of the same material specification as that of the validated product.

For elastomers that are not bonded to a metallic component, the thickness and length of the packing element of the scaled design shall be within 5 % of that of the validated design.

Annex D (informative)

FEA Method for Analyzing a Pressure-containing Liner Hanger Component

D.1 Scope

This annex illustrates a method for analyzing a pressure-containing liner hanger component, such as a liner hanger body or mandrel.

D.2 Summary

Table D.1 is a summary of the presented FEA method.

Table D.1—FEA Method Data

Pressure Type	Geometrical Feature	Wall Thickness	Material Model	Failure Mode	Related Capacity
Internal pressure	Simple cylinder	Thick ($D/t < 20$)	True stress-true strain material data	Von Mises Stress	Pressure at which surface yielding occurs
		Thin ($D/t \geq 20$)	Elastic	Membrane Stress	0.90 x Yield
	Complex cylinder	N/A	True stress-true strain material data	Von Mises Stress	Pressure at which surface yielding occurs
External pressure	Simple/complex cylinder	N/A	True stress-true strain material data	Von Mises Stress	Pressure at which surface yielding occurs
				Instability	0.80 × ultimate collapse
				Drift requirement	Deflect to drift diameter

D.3 Internal Pressure

D.3.1 FEA Models

A 3-D model of the component shall be created which contains all slots, grooves, and other geometrical features. Once the correct geometrical model is created, two FEAs shall be run using the following:

- purely elastic material data; and
- true stress-true strain material data.

D.3.2 Post-processing

Both FEAs are examined, and the points of earliest failure are located (with failure being determined by the presence of yielding). The points of interest are then more closely analyzed in accordance with the following steps to determine the rated capacity.

Determine whether the points of interest are simple thick-walled, simple thin-walled, or complex cylinder.

- Simple thick-walled = (cylinder w/ $D/t < 20$)
- Simple thin-walled = (cylinder w/ $D/t \geq 20$)
- Complex cylinder = (cylinder w/ axial slots)

NOTE 1 Any region of concern containing significant bending stresses produced by slots or other geometrical features is considered to be thick for the purposes of determining component capacity.

Thin wall regions are rated using the purely elastic FEA model.

Membrane stress (average stress through the wall) is examined as pressure is increased.

The pressure that creates a membrane stress equivalent to 90 % of minimum specified yield strength of the material is considered the rated pressure for the thin wall section.

NOTE 2 Ninety percent of the membrane stress is used as the rating criterion because of the catastrophic nature of failure associated with thin-walled members.

Thick wall regions or complex cylinders are rated using the elastic-plastic FEA model.

The von Mises stress is examined at various pressures.

The thick region is rated to the pressure that causes surface yielding due to primary stresses.

NOTE 3 Secondary stresses, which often occur at sharp geometric transitions, are ignored for the purpose of determining static capacity. Although secondary stresses may cause localized yielding, they do not propagate through the component and thus do not contribute to failure. If a localized secondary stress begins to propagate, it is reclassified as a primary stress and considered a possible failure point.

D.4 External Pressure

D.4.1 FEA Model

A 3-D model of the component shall be created that contains all slots, grooves, and other geometrical features. In order to accurately determine external pressure capacity, the FEA model should include the following:

- complete elastic-plastic material behavior (true stress-true strain material data);

NOTE 1 Bilinear material models are not recommended for this method.

- nonlinear geometry analysis;
- ID ovality to initiate geometric instability.

NOTE 2 Ignoring instability can result in overestimated external pressure capacities.

D.4.2 Post-processing

External rated pressure capacities are determined by considering the following failure modes:

Geometric instability—instability is characterized by rapid changes in deflection over small changes in pressure, which can be analyzed by creating a graph of deflection vs pressure at the node of highest deflection. As the pressure

is increased incrementally, the deflection goes near asymptotic at the point of complete collapse. Because collapse due to instability is catastrophic and may occur suddenly, it is recommended that the external pressure capacity is rated at 80 % of the ultimate collapse pressure.

The magnitude of stresses—regions in which yielding occur are rated to the pressure that causes surface yielding due to primary stresses. Secondary stresses, which often occur at sharp geometric transitions, are cautiously ignored for the purpose of determining capacity. Although secondary stresses may cause localized yielding, they do not propagate through the component and thus do not contribute to failure. If a localized secondary stress begins to propagate, it is reclassified as a primary stress and considered a possible failure point.

System drift requirements—if the component is required to remain above certain drift requirements under all loading scenarios, the external pressure capacity is rated at the pressure that causes a component to violate drift requirements.

The rated external pressure capacity is the lowest pressure to cause any of the preceding failure modes, as per Figure D.1.

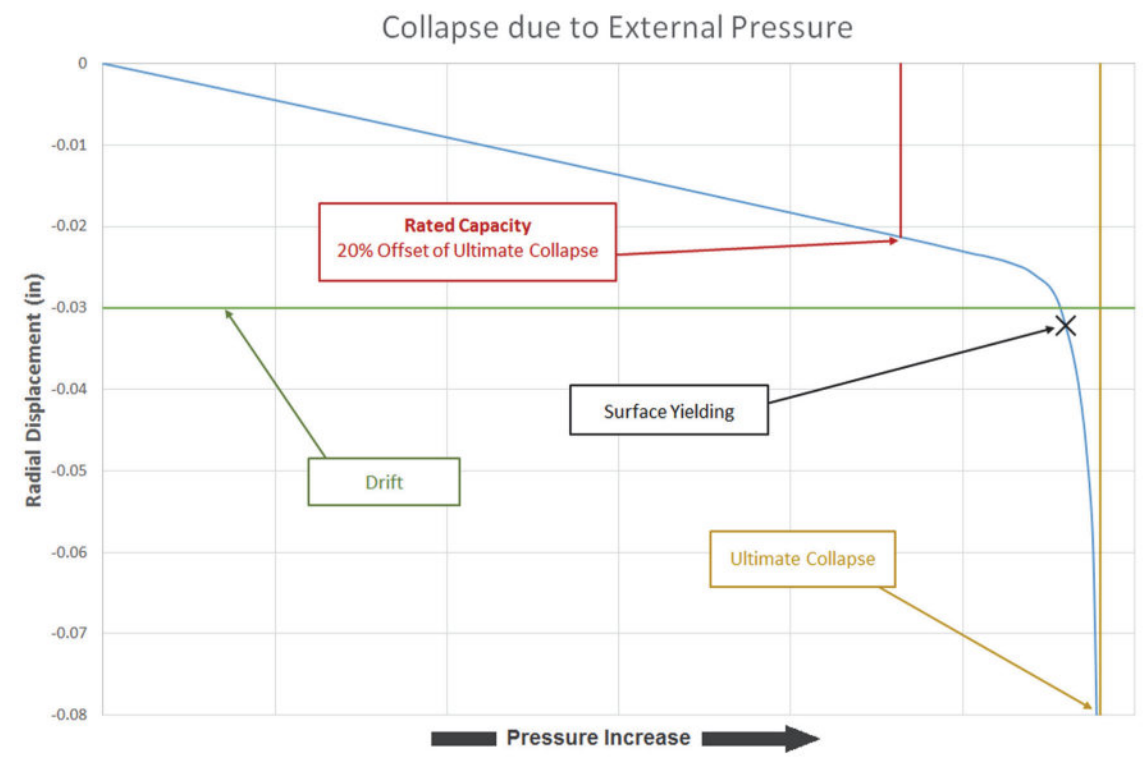


Figure D.1—Example of an External Pressure Plot

Annex E

(normative)

Liner Hanger Running/Setting Tool Requirements

E.1 General

This annex includes the requirements for design verification (including interface capabilities), manufacturing, design validation, design scaling, and reporting requirements for running/setting tools. These tools shall be identified in the operating manuals (7.2.3) and are required for the liner systems to perform as designed.

Not included in the requirements of this annex are contingency tools, milling tools, cementing packoffs, and destructive removal systems.

The activities required by this annex shall be performed by qualified person(s). All results shall conform to the acceptance criteria and be supported by documentation.

Post manufacturing running/setting tool redress, repair, and servicing is not covered by this annex.

E.2 Design Verification

Each running/setting tool design and its operational/interface capability shall be supported by design verification records/reports to the ratings of the tool. Reports shall be approved by the supplier/manufacture's qualified person. The qualified person shall be someone other than the person who prepared the report. Each tool's operational capabilities shall enable the installation of the associated products or systems. Design verification shall include activities such as: design reviews, design calculations, and comparison with similar designs and historical records of defined operating conditions. Verification results shall be approved, and records of the results shall become portion of the tools design documentation.

E.3 Design Validation Requirements

E.3.1 General

The design validation shall conform to API Q1 and support the stated product ratings and capacities.

When tools from the product supplier/manufacture are specified, the interface and performance of the tool design may be validated by a review of reports of the tools' testing and performance ratings. The review shall be documented and approved by the supplier/manufacture's qualified person.

The supplier/manufacture shall have on file material specifications and drawings that show all the applicable dimensions and tolerances of the components contained in the validated product.

Where testing is performed, pre-test and post-test dimensional and visual inspection of critical operational areas, as determined by the supplier/manufacture, shall be conducted, documented, and maintained by the supplier/manufacture. The assembly results and dimensional inspection results shall be approved by a qualified person other than the person performing them, and records of the results shall become a portion of the design documentation.

The running/setting tool design shall conform to the supplier/manufacture-specified acceptance criteria and the requirements of this annex. Failure to do so requires a new set of evaluations, verifications, or validation tests after corrections conforming to the original design requirements are completed.

All testing and evaluations shall be performed to documented procedures and acceptance criteria with approvals. Testing shall conform to the requirements of 7.2 and 7.5, as applicable to requirements for running/setting tools.

E.3.2 Testing During Previous Liner System or Product Validations

A running/setting tool that has had all of its functional capabilities successfully validated to its ratings in the performance of the liner system validation testing shall be considered as meeting the requirements of this annex after the resulting documentation is approved by a qualified person.

Any operational capabilities that have not been validated during the system or product validation testing shall be validated separately to the requirements of this annex.

E.3.3 Testing Requirements

Testing equipment, fixtures (where applicable), and procedures shall conform to the requirements of Section 7.

The design and performance of the test fixture shall replicate the interface of the running/setting tool within its designated system or products and shall not influence the testing results. Design validation by testing shall be done with the applicable system or products, or with a fixture with the equivalent fits, clearances, and minimum required loads as the affected portion of the products or system.

Validation testing shall be discontinued if the running/setting tool or its interface fails to perform within the limits specified, except when such failures are determined to be a result a failure within the test facility alone, and that failure and its correction do not affect the validity of the testing results.

During validation testing of hydraulically operated tools, fluid metering may be used to provide readable control signals during the testing if necessary, to simulate downhole conditions.

E.3.4 Final Design Validation Report

A final report of the design validations shall be prepared and conform to 6.6.5.

E.3.5 Design Changes

Design changes to a validated running/setting tool shall conform to 6.8.

E.3.6 Design Scaling

Scaling may be used to validate variations of a validated running/setting tool of the same design family. A product family is a group of assemblies where the same design configuration principles apply to materials, geometry, and functionality.

The supplier/manufacturer shall establish the maximum stress within the previously validated design of the Type 1 components and in the same components of the scaled design. The mode of stress and same method of calculation(s)/verification(s) shall be applied to the identified components of the base design and the scaled design. For the Type 1 component with the highest design stress factor, the scaled design's stress factors shall not exceed the stress factor of the same component of the validated design.

Design scaling shall be approved by a qualified person. The qualified person shall be someone other than the person who conducted the design scaling, and records of the results shall become a portion of the design documentation.

E.4 Manufacturing Requirement

E.4.1 General

Running/setting tools shall be manufactured to the requirements of 7.4 (as applicable) with a minimum of quality grade QL3.

E.4.2 Assembly Requirements

Any required assembly of the running/setting tool shall follow the supplier/manufacture's documented procedures using components that conform to documented specifications. A bill of materials shall be prepared for each assembly.

E.4.3 Documentation, Data Control, and Operations Manual

The documentation and data control for the assembled tool shall meet the requirements of 7.2, excluding 7.2.4.

E.4.4 Product Identification

Running/setting tools' components shall be permanently identified according to the supplier/manufacture's specifications. The supplier/manufacture's specifications shall define the type, method of application, and location of the identifications.

Annex F

(normative)

Liner Hanger Bearing Validation Testing Requirements

For design validation grade V2 and V1 liner hangers with rotational capability, perform the following actions. This validation can be performed during product, system, or sub-assembly testing.

- 1) Load the bearing to rated dynamic axial capacity.
- 2) Begin bearing rotation. Record the parameters required to determine the initial rotational torque.
- 3) Rotate bearing at a minimum of 20 rpm. Continuously measure the parameters required to determine the rotational torque.
- 4) Apply cooling fluid as specified by supplier/manufacturer.
- 5) Continue rotation while continuously measuring the parameters required to determine the rotational torque.
- 6) Stop test when rotational torque reaches the supplier/manufacture's defined limits. Report elapsed time to test stop and cooling fluid application parameters.

Conduct post-test inspection according to supplier/manufacture procedure.

Prepare test report according to 6.6.5.

Annex G

(informative)

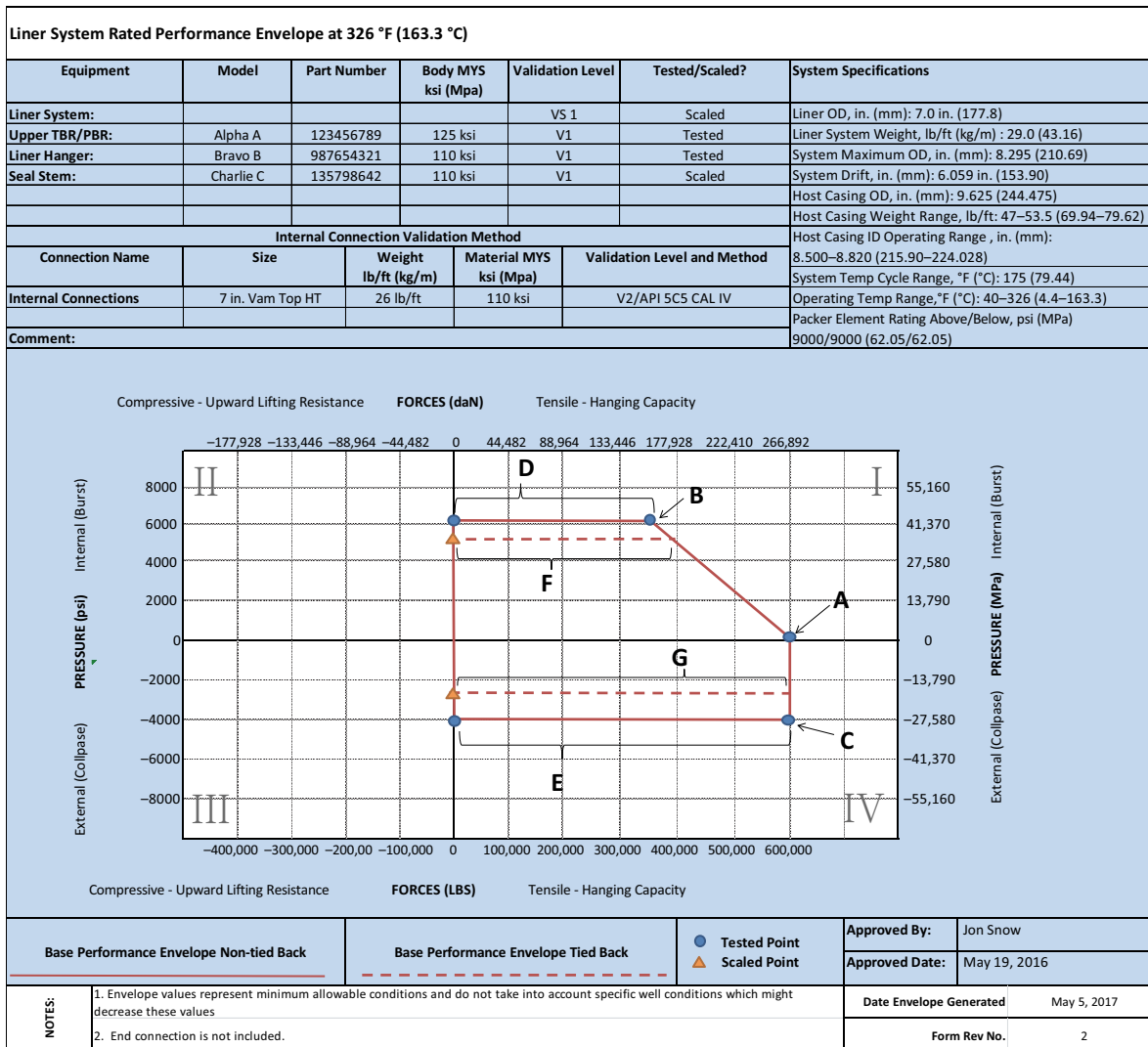
System Performance Envelopes Using Validated Products

G.1 Introduction

Refer to the following pages regarding reference schematics and example envelopes. Product envelopes and test data points based on individual product validation shall be combined to generate an overall system envelope and shall consider tied back and non-tied back conditions. System combinations along with envelope intersection points are outlined in the following section.

G.2 Example of Performance Envelope for Seal Assembly—TBR/PBR—Liner Hanger for Non-tied Back and Tied Back Conditions

The example, shown in Figure G.1, depicts the following pressure and loading conditions as shown on the performance envelope.



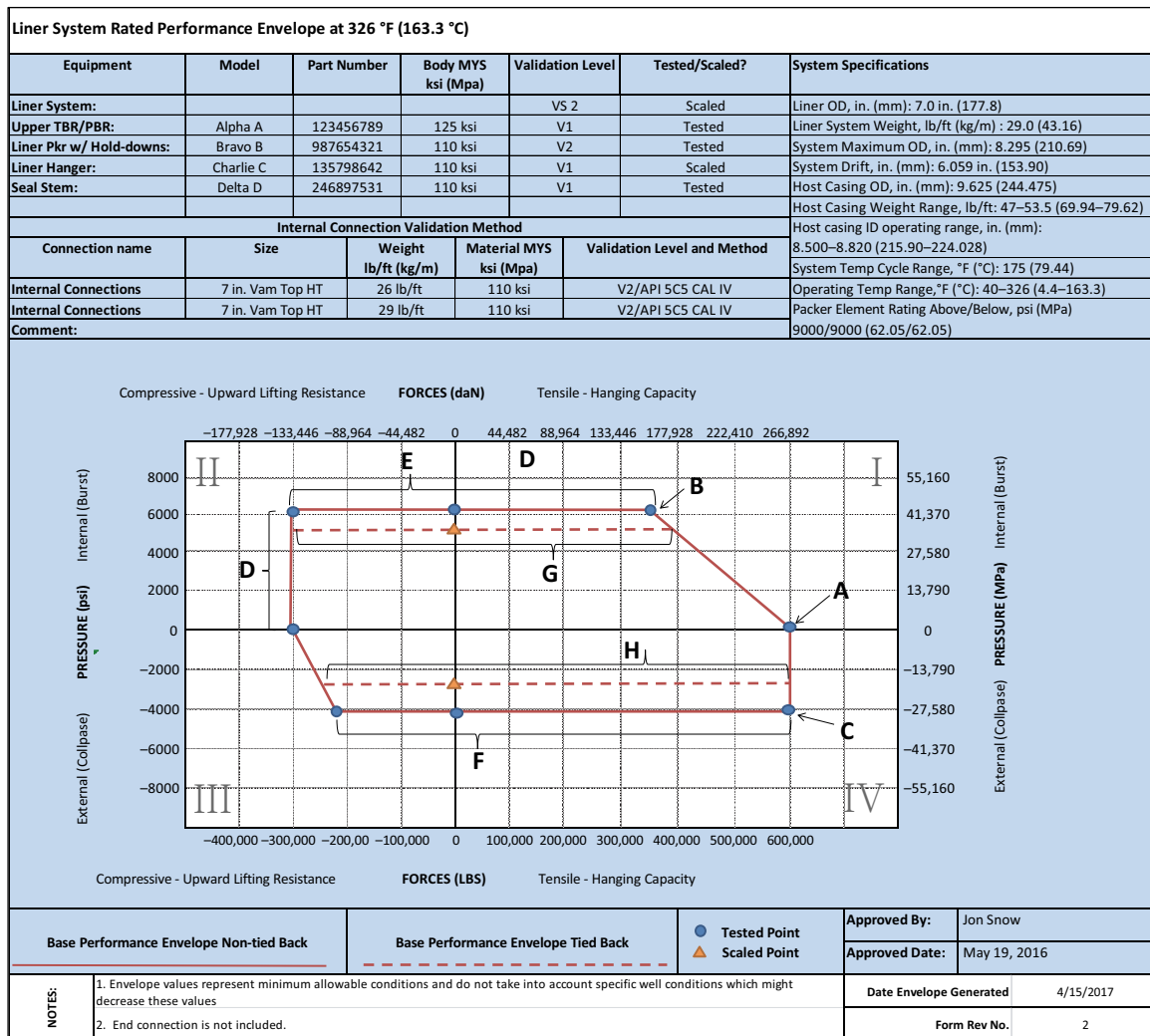
Key

- A Maximum tensile (hanging) capacity without pressure differential
- B Maximum tensile (hanging) capacity with maximum system internal (burst) pressure
- C Maximum tensile (hanging) capacity with maximum system external (collapse) pressure
- D Maximum internal (burst) pressure with no load
- E Maximum external (collapse) pressure with no load
- F Maximum internal pressure with no load in tied back condition
- G Maximum external pressure with no load in tied back condition
- I Quadrant 1
- II Quadrant 2
- III Quadrant 3
- IV Quadrant 4

Figure G.1—System Performance Envelope Example—Illustrating Tied Back and Non-tied Back Conditions

G.3 TBR/PBR—Liner Packer with Hold-downs—Liner Hanger, Non-tied Back, and Tied Back conditions

The example in Figure G.2 depicts the following pressure and loading conditions as shown on the performance envelope.



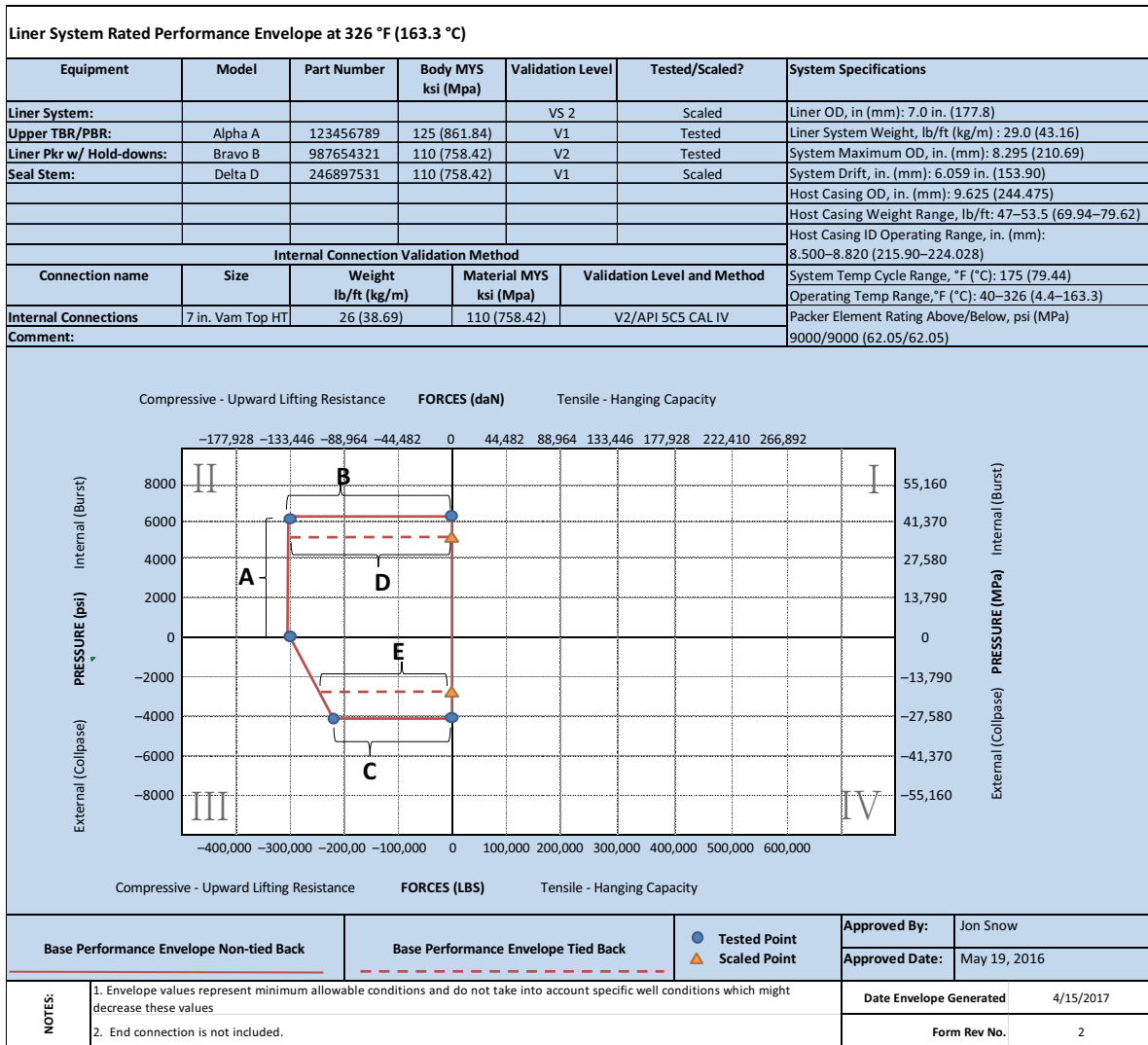
Key

- A Maximum tensile (hanging) capacity without pressure differential
- B Maximum tensile (hanging) capacity with maximum system internal (burst) pressure
- C Maximum tensile (hanging) capacity with maximum system external (collapse) pressure
- D Maximum upward lifting resistance of the system
- E Maximum internal pressure rating in non-tied back condition
- F Maximum external pressure rating in non-tied back condition
- G Maximum internal pressure rating in tied back condition
- H Maximum external pressure rating in tied back condition
- I Quadrant 1
- II Quadrant 2
- III Quadrant 3
- IV Quadrant 4

Figure G.2—System Performance Envelope Example—Illustrating Liner Packer with Hold-downs in Tied Back and Non-tied Back Conditions

G.4 TBR/PBR—Packer—Seal Assembly

The example in Figure G.3 depicts the following pressure and loading conditions as shown on the performance envelope.



Key

- A Maximum upward lifting resistance of the system
- B Maximum internal pressure rating in non-tied back condition
- C Maximum external pressure rating in non-tied back condition
- D Maximum internal pressure rating in tied back condition
- E Maximum external pressure rating in tied back condition
- I Quadrant 1
- II Quadrant 2
- III Quadrant 3
- IV Quadrant 4

Figure G.3—System Performance Envelope Example—Illustrating Packer—Seal Assembly in Tied Back and Non-tied Back Conditions

Annex H (normative)

Sampling Plans

H.1 General

When sampling is permitted, the requirements of this section shall apply, including the alternatives.

H.2 Sampling Requirement

Table H.1 shall be used in selecting the samples to be inspected. When sampling is permitted in the quality grade table the requirements of this section apply except where alternatives are defined.

If the lot size is smaller than the sample size, then all the items in the inspection lot shall be inspected.

Each sample that is inspected shall meet the supplier/manufacturer-defined inspection criteria.

Table H.1—Inspection Sample Sizes

Inspection Lot Size	Required Sample Size
1—5	2
6—10	3
11—25	4
26—50	7
51—150	11
151—280	13
281—500	16
501—1200	19
NOTE Larger lots shall conform to ASQC H1331 (Fifth Edition) with an index of 2.5.	

H.3 Randomness

Each sample shall be selected at random from the inspection lot. Randomness is achieved when each unit within the lot has an equal chance of being selected as the sample(s) to be inspected.

H.4 Inspection Limits

An inspection lot is defined as those units that consist of a single type, grade, class, size, and composition, manufactured under essentially the same conditions at the same time and presented for inspection at the same time.

NOTE Failure to select the sample pieces randomly may introduce incorrect sampling results.

The identification of a single nonconforming unit rejects the entire lot. The units within a rejected lot shall be dispositioned according to the applicable QMS. In every case, all units from a rejected lot shall be re-evaluated before use.

H.5 Alternative Methods

Alternately, other national or international sampling standards may be used, provided that the acceptance number (c) is zero and the average outgoing quality limit (AOQL) is the same or better than the values in ASQC H1331 for an index value of 2.5. The requirements of H.1 through H.5 also apply.

NOTE When using other sampling plans such as ANSI/ASQ Z1.4 or ISO 2859-1, particular attention should be paid to the notes associated with the tables, as they can change the sample size for a given lot.

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- [7] API Standard 20C, *Closed Die Forgings for Use in the Petroleum and Natural Gas Industry*
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- [9] ANSI/ASQC Z1.4, *Sampling Procedures and Tables for Inspection by Attributes*
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