Specification for Downhole Well Test Tools and Related Equipment

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Foreword

This specification has been developed by users/purchasers and suppliers/manufacturers of downhole well test tools intended for use in the petroleum and natural gas industry worldwide. This specification is intended to give requirements and information to both parties in the selection, manufacture, testing, and use of the tools named within the scope. Furthermore, this specification addresses the minimum requirements with which the supplier/manufacturer is to comply so as to claim conformity with this specification.

Users of this specification should be aware that requirements above those outlined in this specification 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 may be particularly applicable where there is innovative or developing technology. Where an alternative is offered, the supplier/ manufacturer should identify any variations from this specification and provide details.

This first edition of the specification has been authored in an effort to cover the prominent range of well test tools. Additionally included are requirements for service centers to ensure these products perform as designed when maintained as defined therein. It is recognized that these requirements may merit some refinement following their utilization.

Included in this specification are nine annexes (Annexes A through I), all of which are normative except Annexes H and I. Where referenced, these annexes provide mandatory requirements for conformance to this specification.

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Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, DC 20005, standards@api.org.

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Introduction

This specification applies to downhole well test tools that prior to this publication were not addressed by standards or specifications. Additionally, this specification defines requirements for service centers from which these tools are typically provided and maintained.

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

This specification has been structured with a single grade of quality control requirements and three grades of design validation. These validation grades provide the user/purchaser the choice of requirements to meet their preference or application. Design validation grades V3 (well test tools) and V3-TP (well test packers) are the minimum grades, and V1 (well test tools) and V1-TP (well test packers) are the most stringent grades.

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

Annexes are as follows:

— Annex A—Validation Requirements for Downhole Well Test Tools and Related Equipment;

— Annex B—Factory Acceptance Testing;

— Annex C—Service Center Requirements;

— Annex D—Performance Rating Envelopes;

— Annex E—Well Testing Packer Requirements;

— Annex F—Electronic and Electrical Components, Subcomponents, and Systems Requirements;

— Annex G—Testing Surface Safety Valve Requirements;

— Annex H—Applications Overview;

— Annex I—Operational Recommendations.

The international system of units (SI) is used in this specification; however, U.S. customary units are also shown for reference.

Users of this specification should be aware that requirements above those outlined in this specification 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 may be particularly applicable where there is innovative or developing technology. Where an alternative is offered, the supplier/manufacturer should identify any variations from this specification and provide details.

Specification for Downhole Well Test Tools and Related Equipment

1 Scope

This specification provides the requirements for downhole well test tools and related equipment as they are defined herein for use in the petroleum and natural gas industries. Included are the requirements for design, design validation, manufacturing, functional evaluation, quality, handling, storage, and service centers. Tools utilized in downhole well test operations include tester valves, circulating valves, well testing packers, safety joints, well testing safety valves, testing surface safety valves (TSSVs), slip joints, jars, work string tester valves, sampler carriers, gauge carriers, drain valves, related equipment, and tool end connections.

This specification does not cover open hole well test tools, downhole gauges, samplers, surface equipment, subsea safety equipment, perforating equipment and accessories, pup joints external to well test tool assemblies, work string and its connections, conveyance or intervention systems, installation, control and monitoring conduits, and surface control systems.

A downhole well test is an operation deploying a temporary completion in a well to safely acquire dynamic rates, formation pressure/temperature, and formation fluid data. Downhole well test tools are also used in operations of well perforating, well shut-ins, circulation control of fluids, and stimulation activities. This document covers the downhole tools used to perform these operations; however, the operational requirements of performing these operations are not included.

2 Normative References

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

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

ASME *Boiler and Pressure Vessel Code* (*BPVC*) [1], *Section IX: Welding and Brazing Qualifications*

ASNT SNT-TC-1A [2], *Recommended Practice for Personnel Qualification and Certification in Non-destructive Testing*

ASTM E10 [3], *Standard Test Methods for Brinell Hardness Testing of Metallic Materials*

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

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

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

ISO 3601-1 [4], *Fluid power systems—O-rings—Part 1: Inside diameters, cross-sections, tolerances and designation codes*

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

ISO 6506 (all parts), *Metallic materials—Hardness test—Brinell test*

[1] ASME International, 2 Park Avenue, New York, New York 10016-5990, www.asme.org.
[2] American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, Ohio 43228, www.asnt.org.
[3] ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.
[4] International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211 Geneva 20, Switzerland, www.iso.org.

ISO 6507 (all parts), *Metallic materials—Vickers hardness test*

ISO 6508 (all parts), *Metallic materials—Rockwell hardness test*

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

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

NACE MR0175 [5]/ISO 15156 (all parts), *Petroleum, petrochemical, and natural gas industries—Materials for use in H_2S-containing environments in oil and gas production*

3 Terms and Definitions

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

3.1
absolute pressure
Hydrostatic pressure plus applied pressure.

3.2
absolute pressure dependency
A condition in which a tool has an atmospheric or nonpressure balanced chamber, or seals having multiple sealing elements in a common seal gland, or seal systems having multiple seal glands where an atmospheric space can exist between glands.

3.3
ambient temperature
Prevailing temperature at test site.

3.4
assembly
Product made up of more than one component.

3.5
barrier
Obstacle to prevent flow whose performance can be verified.

3.6
base design
Design of a specified size, type, and model of a downhole well test tool that meets the requirements of this specification.

3.7
batch lot
Material or components that have undergone the same process or series of processes and are traceable to one batch of material.

3.8
bill of materials
Controlled list of components of an assembly.

[5] NACE International (formerly the National Association of Corrosion Engineers), 1440 South Creek Drive, Houston, Texas 77084-4906, www.nace.org.

3.9
brazing
Process of joining metal using a nonferrous filler, the filler having a melting point below that of the metal being joined.

3.10
circulating valve
Downhole device to provide communication/isolation between annulus and work string.

3.11
closure mechanism
A system of parts that operate to close the tool, such as to close the inside diameter (ID), or to close on opening to/from the ID to the outside diameter (OD).

3.12
coating
Permanent deposition of a material onto the surface of a part to enhance its surface properties such as improving corrosion protection, wear resistance, or reducing friction.

3.13
common hardware
Nontraceable items such as nuts, bolts, set screws, and spacers.

3.14
crossover
Tubular element with two different threaded connections.

3.15
design validation
Process of proving a design by testing to demonstrate conformity of the product to design requirements.

3.16
design verification
Process of examining the result of a given design or development activity to determine conformity with specified requirements. (See 6.6.)

3.17
differential pressure
Difference between internal and external pressure or the difference in pressure across a closure mechanism or a packer element.

3.18
downhole well test tool
A device used in combination with other devices to perform a downhole well test.

3.19
drain valve
Downhole device that manually relieves internally trapped pressure at surface.

3.20
drawdown
Reduction in borehole pressure below formation pressure.

3.21
drift
Bar utilized to verify the passage of a specified diameter and length through a well test tool.

3.22
environment
Set of conditions to which the product is exposed.

3.23
external pressure
Pressure acting on the outer diameter of a tool.

3.24
fit
Geometric relationship between parts including the tolerance criteria used during the design of a part and its mating parts.

3.25
functional specification
Features, characteristics, process conditions, boundaries, and exclusions defining the performance of the tools.

3.26
functional test
Test process performed to confirm proper operation of a tool.

3.27
gauge carrier
Tool used to convey gauges downhole.

3.28
gauge, downhole
A device designed to measure downhole parameters such as pressure and/or temperature.

3.29
hardness
Material surface property as determined from a test such as Rockwell, Brinell, Vickers, etc.

3.30
heat lot
Material or components that are traceable to one heat of metallic material.

3.31
heat treatment
Controlled heating and cooling of materials for the purpose of changing mechanical properties.

3.32
indication
An identified discontinuity or flaw in a material determined by a nondestructive material inspection technique.

3.33
informative
Information that is meant to enlighten the user/purchaser or supplier/manufacturer, without containing requirements.

3.34
interchangeability
Ability to replace one component/subassembly with another component/subassembly without affecting operation or function.

3.35
internal pressure
Pressure acting on the internal diameter of a tool.

3.36
jar
A tool used to deliver an axial impact load to the downhole string.

3.37
job
One deployment of downhole tools to planned depth and retrieval through the rotary table.

3.38
job lot
Batch of material or components that have undergone the same process or series of processes; this may include more than one heat of metallic components.

3.39
legacy design
A tool design that was developed and manufactured prior to the publication of this specification.

3.40
load bearing
Device and/or part that supports or transmits a load.

3.41
manufacturing
Processes and actions performed that are necessary to provide finished component(s), assembly(ies), and related documentation.

3.42
model
Tool design with unique components and operating characteristics, which differentiate it from other tool designs of the same type.

3.43
nondestructive examination
NDE
An inspection technique used to evaluate a part without causing permanent damage. Common techniques include magnetic particle inspection (MPI), dye penetrant inspection (DPI), or X-ray.

3.44
normative
Information or procedures that shall be used by the user/purchaser or supplier/manufacturer to comply with this specification.

3.45
operating manual
Publication issued by the supplier/manufacturer, which contains detailed data and instructions related to the design, installation, operation, and maintenance of a particular tool.

3.46
operating temperature range
Range defined by the minimum and maximum operating temperatures for tools as specified by the supplier/manufacturer.

3.47
operational cycle
A single complete execution of a tool's operating mechanism, starting and finishing at the same tool state.

3.48
overlay
Deposition of new material over an existing material.

3.49
packer element sealing system
Components consisting of elastomeric elements and anti-extrusion devices comprising a sealing system.

3.50
perforating equipment and accessories
Devices used to create holes in the casing to connect the formation to the casing ID and accessories such as circulating subs, tubing releases, shock absorbers, Y block assemblies, blast joints, gun hanger systems, and swivel subs.

3.51
plating
Deposition of a thin layer of metal onto a surface by techniques such as electroless or electroplating, vapor deposition, and sputter deposition.

3.52
pressure retaining
Device or part that is stressed due to the effects of a differential pressure acting on its boundary.

3.53
pressure reversal
Change from predominant pressure in the annulus to predominant pressure in the work string bore or vice versa.

3.54
pump-through
Capability of a device/tool with a closure mechanism to be partially opened by the application of differential pressure in the opposite direction of sealing, thus allowing fluid to be pumped through the tool.

3.55
pup joint
Short tubular element used to join two threaded connections.

3.56
qualified person
An individual or individuals with competencies gained through training and experience as measured against established requirements, such as standards or tests that enable the individual to perform a required function.

3.57
rated pressure
Maximum supplier/manufacturer-defined pressure limit; for absolute, external, internal, and barrier differential pressures.

3.58
related equipment
Any other downhole tool or equipment that would be included or necessary for downhole well test tools operations not included in another standard or specification.

3.59
room temperature
Temperature typically between 15 °C (60 °F) and 26 °C (80 °F).

3.60
run
Act of deploying downhole tools below the rotary table after connection to the work string.

3.61
safety joint
A device to allow an intentional controlled separation of the work string or bottomhole assembly (BHA).

3.62
sampler carriers
Tool used to convey fluid samplers downhole.

3.63
sealing element
Device preventing passage (i.e. communication) of liquid and/or gas across the interface in which it is placed.

3.64
service center
A location where equipment is inspected, repaired, and tested to maintain supplier/manufacturer's specifications.

3.65
shear device
Component designed to part under a predetermined load.

3.66
slip joint
A tool having a sealed telescoping joint designed to accommodate tubing expansion and contraction.

3.67
special feature
Specific additional functional capability not specifically described in the validation profile test sequences in Annex A.

3.68
stick-up
Distance between the rotary table and the lower most part of the surface test tree.

3.69
stress relieving
Controlled heating of material to a predetermined temperature for the purpose of reducing any residual stresses.

3.70
subassembly
Subordinate unit consisting of two or more components assembled for incorporation as an integral portion of a tool, which may be independently performance tested before its integration.

3.71
substantive change
Change that potentially affects the performance or rating of the tool in the intended service as evaluated by a qualified person at the supplier/manufacturer.

3.72
surface treatment
Process designed to alter the surface of a material to achieve a desired property such as hardness or corrosion resistance.

3.73
tester valve
Downhole device having open and closed positions providing communication/isolation with the formation.

3.74
testing surface safety valve
TSSV
Fail-closed surface-controlled safety valve placed near surface below the rotary (typically on land and jack-up operations) that performs a barrier function with pump-through and chemical injection capability.

3.75
tool
Device that is designed to perform specific function(s) within the well testing BHA.

3.76
tool end connection
Uppermost and lowermost interface/connection of the downhole well test tool.

3.77
type
A product with unique characteristics or functionality, which differentiates it from other equipment.

3.78
visual inspection
Visually examining for a variety of surface flaws, such as corrosion, contamination, surface finish, and surface discontinuities.

3.79
welding
Process of joining metal by bringing abutting surfaces to a molten state with or without the use of a filler material.

3.80
well barrier
An envelope of one or more well barrier elements that prevents fluids from flowing unintentionally from the formation or well into another formation or to the surface.

3.81
well barrier element
A pressure and flow containing component that relies on other component(s) to create a well barrier.

3.82
well testing packer
A sealing and load-bearing device that isolates the formation from annulus fluids and conforms to Annex E.

3.83
well testing safety valve
A downhole device that is designed to close, typically with annulus overpressure, to isolate the formation from the work string.

3.84
work string
Tubular conduit used to convey well test tools downhole and provide a flow path for reservoir fluids to surface.

3.85
work string tester valve
A downhole device that is designed to integrity test the BHA and work string.

4 Abbreviations

AWS	American Welding Society
BHA	bottomhole assembly
BOP	blowout preventer
COC	certificate of compliance (or conformance)
DST	drill stem test
ESD	emergency shutdown
FAT	factory acceptance testing
HPHT	high pressure, high temperature
HPU	hydraulic power unit
HSE	health, safety, and environment
ID	inside diameter
LCM	lost control material
MPI	magnetic particle inspection
MTR	material test report
NDE	nondestructive examination
NORM	naturally occurring radioactive material
NORSOK	Norsk Sokkels Konkuranseposisjon (Norwegian Standards Organization)
NRV	nonreturn valve
OD	outside diameter
OSHA	Occupational Safety and Health Administration
PED	Pressure Equipment Directive
POOH	pulling of out hole
RIH	running in hole
TCP	tubing conveyed perforating

TSSV	testing surface safety valve
TMD	total measured depth
TVD	true vertical depth
WPS	welding procedure specification

5 Functional Specification

5.1 General

The supplier/manufacturer shall establish the functional requirements for tools that conform to this specification. The functional requirements are typically derived from input provided by potential user/purchasers and shall be documented to conform to the applicable requirements of Section 5 herein.

5.2 Functional Characteristics

The functions and characteristics shall include, but not be limited to the following, as applicable (some tools may have multiple functions and characteristics) for each required tool (F = function, C = characteristics).

a) *Circulating Valve*—(F) Provides communication between annulus and tubing. (C) Number of cycles, flow area, control means and limits, isolation below circulating ports.

b) *Drain Valve*—(F) Relieves trapped pressure from within the work string at surface. (C) None.

c) *Gauge Carrier*—(F) Device used to convey downhole gauges. (C) Eccentric/concentric flow bore, porting options, gauge model compatibility/quantity and mounting configuration.

d) *Jar*—(F) Applies an impact load to the test string. (C) Actuation means, number of cycles.

e) *Related Equipment*—Other tools that are part of the test tool BHA.

f) *Safety Joint*—(F) Allows intentional, controlled separation within the test string. (C) Actuation and recovery method.

g) *Sampler Carrier*—(F) Device used to convey downhole fluid samplers. (C) Actuation means, eccentric/concentric flow bore, sampler model compatibility/quantity and mounting configuration.

h) *Work String Safety Valve*—(F) Device used to shut in the well should there be a leak in the work string above the safety valve. (C) Actuation means, closure mechanism.

i) *Testing Surface Safety Valve*—(F) A near-surface emergency safety device that provides isolation in the direction of flow. (C) Chemical injection, pump-through capability, control means, number of cycles, cutting capability.

j) *Slip Joint*—(F) Telescoping device that allows for axial expansion and contraction of the test string. (C) Pressure balance.

k) *Tester Valve*—(F) Controls flow (open or closed) and provides downhole communication/isolation with the formation. (C) Number of cycles, option of lock open feature, control means and limits.

l) *Well Testing Packer*—(F) Isolates the annulus from above and formation from below. (C) Setting, anchoring and retrieval means (including fishing), flow bypass.

m) *Work String Tester Valve*—(F) Provides a means to pressure test the work string above. (C) Isolation means, control means, number of cycles, filling capability.

5.3 Design Considerations

5.3.1 Well Parameters

The following well parameters shall be considered when establishing the functional characteristics of a tool:

a) well location and rig type (land, platform, subsea);

b) air gap, water depth, true vertical depth (TVD), total measured depth (TMD);

c) blowout preventer (BOP) size, type, configuration;

d) size, mass (weight), grade, material, connection type of the casing and work string;

e) casing and/or work string architecture, trajectory, deviations, restrictions, maximum dog leg severity;

f) casing pressure capability;

g) general wellbore fluid types and composition.

5.3.2 Operational Parameters

The following anticipated operational parameters shall be considered when establishing the functional characteristics of a tool:

a) formation fluid composition;

b) pressure range—for formation and external, internal, and differential pressures of tools;

c) temperature range;

d) flow rate and solids content;

e) underbalance/overbalance annulus;

f) drawdown;

g) test duration;

h) loading conditions for planned test including pressures, temperatures, tension/compression, torque, bending, and intermittent conditions such as pressure testing;

i) well pumping operations—acid composition, sand/proppant description, fluid flow rate, proppant/fluid ratio or sand/fluid ratio, pressure, temperature and exposure time, and any other chemicals.

5.3.3 Environmental Compatibility

The following parameters shall be considered when establishing the functional characteristics of a tool:

a) production/injection/annular fluid chemical and physical composition that may affect tool performance such as sand production, scale, water, H_2S, CO_2, waxes, asphaltenes, pH, amines, and others that may be provided by user/purchaser(s);

b) environmental conditions/changes during transportation, storage, and at surface prior to and during deployment;

c) applicable regulations and restrictions.

It is the equipment user/purchaser's responsibility to ensure that selected materials in a tool design are suitable for job-specific service environments.

NOTE In the event that the user/purchaser believes a specific well environment requires conformance to NACE MR0175/ISO 15156, the user/purchaser can include that requirement in the individual job contract.

5.3.4 Compatibility with Related Well Equipment

The following information, as applicable, shall be specified to ensure the compatibility of the downhole well test tools with the related well equipment:

a) downhole well test tool sizes and connections to the work string;

b) requirement(s) for continuity of flow path and/or through bore access (size, length, etc.), passage of conduits (electrical/hydraulic, etc.) between tool's OD and casing ID, and/or open hole ID restrictions;

c) details of any devices to be run through the downhole well test tools; provide details such as size, type, configuration, and means of conveyance;

d) drifting requirements;

e) internal receptacle profile(s) required in the downhole well test tools for receiving related well equipment, such as sealing bore, dimension(s), eccentricity, and respective locations.

5.4 Design Validation Grade Selection

Three design validation grades are designated for well test tools (V3, V2, V1), and three corresponding grades are designated for well testing packers (V3-TP, V2-TP, V1-TP). The validation grades for packers are uniquely designated with the suffix -TP to differentiate them from packer validation grades in other API specifications that may differ in their definition and requirements.

The design validation grade shall be selected from Table 1 for each design to be provided. These validation grades are proof of design evaluations that are performed on the base design. The detailed requirements for each validation grade are contained in Annex A (well test tools) and Annex E (well test packers). A summary of the validation testing coverage required by tool type and grade is presented in Table1. For more details on validation grade requirements, see Table A.1 and Table E.1.

Table 1—Design Validation Grade Summary

V1 and V1-TP Design validation with gas test medium	Each design conforms to the validation requirements of V2 as defined in Annex A for well test tools or V2-TP as defined in Annex E for well test packers, in addition to the V1/V1-TP specific requirements, utilizing a gas test media as defined in those annexes.
V2 and V2-TP Design validation with liquid test medium	Each design conforms to the validation requirements, including pressure testing using a liquid test media as defined in Annex A for well test tools (V2) or Annex E for well test packers (V2-TP).
V3 and V3-TP Legacy design validation	To address legacy designs, design verifications are required and are comprised of design calculations and a combination of documented field history performance in an environment similar to that of the functional requirements and/or testing demonstrating that all design limits are verified.

5.5 Quality Grade

A single, common quality grade shall apply to all tools provided under this specification. The detailed quality requirements are contained in Section 7 and summarized in Table 2.

6 Technical Specification

6.1 General

The supplier/manufacturer shall establish a technical specification that conforms to the functional requirements.

6.2 Technical Characteristics

Downhole well test tools and related equipment shall perform in accordance with the functional requirements as stated in Section 5 and within the limitations defined in the product-specific operating manual.

6.3 Design Criteria

6.3.1 General

Downhole well test tools and related tool designs shall perform in a predictable and repeatable manner in accordance with their respective technical specification and meet the design validation requirements of Annex A, Annex E, Annex F, or Annex G, as applicable (see 6.7). Approval of the design shall be performed and documented by a qualified person(s) other than the person(s) who created the design.

6.3.2 Design Requirements

6.3.2.1 General

Design requirements shall include the functional specification and other pertinent requirements upon which the design is based. The following ratings shall be established for each downhole well test tool:

a) absolute internal (bore) pressure;

b) absolute external pressure;

c) maximum differential pressure(s);

d) other pressure restrictions applicable to the tool, such as differential pressure across a closure mechanism (from below, above, inside, outside);

e) operational temperature range(s), including temperature drop;

f) operational cycles per job;

g) targeted casing size (packers);

h) nominal tool size, such as OD, ID, and length;

i) pressure drop at a defined flow rate(s) at ambient temperature with water on ported tools;

j) tensile rating, including tool end connections;

k) compressive rating, including tool end connections (straight compression without bending/buckling);

l) other operational/environmental capabilities and limitations, including storage and transport temperature ranges, as applicable.

Items a) through g) shall be established by validation testing in accordance with the applicable annexes. Items h) through l) shall be established by validation testing and/or verification.

When establishing the rated pressures and load capabilities, material selections shall consider temperature and environment. Where applicable, specialized and/or intermittent conditions, such as pressure testing with temporary test caps, shall also be considered in the design.

Downhole well test tools and components shall be manufactured in accordance with the process, drawings, and specifications of the product that passed the applicable validation test. Any changes shall conform to 6.10.

Electronic and electrical components, subcomponents, and systems shall conform to Annex F.

TSSVs shall conform to Annex G.

If applicable, a table shall be supplied that establishes ratings with the validated design and material variations. The tool's capabilities within those variations shall be stated. A table such as this may contain information on packer element options, gauge ring ODs, and sealing system options.

6.3.2.2 Design Considerations

Downhole well test tool designs shall take into consideration the effects of temperature (range and duration) on all components. The upper temperature limit shall be the lowest high-temperature rating of any component of the downhole test tool. The lower temperature limit shall be the highest low-temperature rating of any component. Derating of metal mechanical properties as a function of temperature shall be accounted for in the design in accordance with the supplier/manufacturer's documented practice and based upon documented material testing.

Downhole well test tools shall be designed to avoid unintended trapped pressure being brought back to surface. Individual downhole well test tools shall be designed with the ability to safely relieve inadvertently trapped pressure during disassembly of the tool.

Downhole well test tool design shall consider the effects of exposure to fluid(s) identified in the functional requirements on all components. These designs shall consider the effects of substances routinely encountered in well testing operations, such as debris, H_2S, CO_2, acids/alkalines, chlorides, and corrosion inhibitors.

The entire operational mission profile of the tool, such as storage, transportation, serviceability, environmental exposure, downhole operation, bending, and transitional environmental conditions (such as low subsea temperature), shall be used to develop design requirements for new tools.

A failure modes risk assessment shall be conducted for each new tool design.

Welding on tension-loaded components is not a preferred joining method. Welding should generally be avoided. When welding is performed, it shall comply with 6.4.2.3.

6.3.2.3 Design Margins

The supplier/manufacturer shall apply a design margin to the design of each component or assembly using a documented methodology and practice that where appropriate has its origins within a national or international standard that is directly applicable to the component or system that is evaluated. The design margin shall consider maximum combined stresses resulting from operational loads and conditions prescribed by the functional requirements.

Design margins establish a level of performance capability to compensate for the rated loading and the intrinsic variations in the mechanical properties such as yield strength, ultimate strength, endurance strength, and modulus of elasticity. The ability to quantify stresses in components and assemblies with complex geometries shall be considered in establishing a design margin. The documented design margins shall be utilized in the creation of component or assembly capabilities or ratings.

The design of the component or tool shall be based upon the minimum material thickness, minimum allowable yield strength at the maximum rated temperatures (including temperature cycles), and operational loads.

The rating of an assembled design shall be determined by the lowest capability or performance potential of any component of the assembly after the application of the design margin. Design extensions, replacement components, and design revisions shall conform to the design margin, design assumptions, and design analysis methods that were applied to the base component or assembly.

The design shall be validated in accordance with Annex A, Annex E, Annex F, and Annex G, as applicable. All design validation results and tool identifications shall be recorded in the tool's design documentation and approved by a qualified person(s). When a sufficient design margin is not verified by calculation, it is acceptable that it be confirmed by validation.

6.3.2.4 Interchangeability of Components

The design, act of tolerancing, and manufacturing of downhole well test tool components shall be conducted so that interchangeability of components and/or subassemblies of separately manufactured tools is possible without affecting the performance of the assembled tool that has met the requirements of design validation.

6.4 Materials

6.4.1 General

Materials for each component shall be stated by the supplier/manufacturer and shall be suitable for the environmental conditions defined in the functional specification. The supplier/manufacturer shall have documented specifications for all materials and materials shall comply with these requirements. Material specification properties shall be reported at room temperature unless specified otherwise.

Nonsubstantive material substitutions from those materials used in the validation of tested tools may be allowed without validation testing, providing the supplier/manufacturer's selection criteria for these substitutions shall be verified and the substituted material shall conform to the validated design, functional specifications, technical specifications, and ratings. Material substitutions require approval by a qualified person(s) and the supporting information incorporated into the design documentation. Substantive material changes (metallic and nonmetallic) shall conform to the provisions of 6.3 and 6.10 and the supporting information shall be incorporated into the design documentation.

Seal materials can be substituted after having passed the requirements of validation testing as specified in A.3.6.6 or E.7 as applicable.

6.4.2 Metals

6.4.2.1 General

The final condition of metallic materials used in the manufacture of downhole well test tools shall comply with the material specifications, which shall include the following items:

a) chemical composition limits;

b) heat treatment/conditions;

c) mechanical property limits, including as a minimum:

   1) tensile strength;

   2) yield strength (transverse and longitudinal as applicable);

   3) elongation;

   4) hardness;

   5) toughness, where applicable and as defined by the supplier/manufacturer.

For each item, an applicable industry-accepted test standard/method shall be specified.

This provision does not apply to common hardware, nor does it apply to engineered components that are validated independently, such as rupture discs and shearable devices.

6.4.2.2 Cast and Forged Component Requirements

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. The following shall be completed.

a) Each cast or forged component shall be surface nondestructive examination (NDE) inspected on 100 % of its visually accessible surfaces after final processing such as final machining or heat treatment.

b) Each cast or forged component shall be hardness tested at the supplier/manufacturer's defined location(s) on the part conforming to a standard such as ASTM E10, ASTM E18, ASTM E384, or equivalent internationally recognized standard applicable to the material and component. Representative material samples may be utilized if required by the product design.

c) All castings and forgings require a first article qualification, which shall as a minimum include mechanical properties, heat treat condition and chemistry, volumetric NDE, surface NDE, and 100 % dimensional inspections.

For the requirements of 6.4.2.2, bar and tube stock are not considered to be cast or forged components.

6.4.2.3 Welding and Brazing

Welding and brazing procedures, activities, and personnel qualifications are required in accordance with ASME *BPVC* Section IX. Materials and practices not listed in the ASME *BPVC* Section IX shall be qualified in accordance with the methods of ASME *BPVC* Section IX and approved by a qualified person(s).

Welding shall be governed by a qualified welding procedure specification (WPS). The WPS shall be qualified per Section IX of the ASME *BPVC* or other equivalent industry standard. Weldments for sour service applications shall meet all the requirements of NACE MR0175/ISO 15156. The welding specification shall include requirements for:

a) postweld heat treatment and/or stress relief;

b) welding process;

c) defined nondestructive testing method(s), acceptance criteria, and documentation.

Welding consumables shall conform to American Welding Society (AWS) or supplier/manufacturer's written specifications as specified in the WPS. The supplier/manufacturer shall have a written procedure for selection, storage, control, and use of welding consumables.

6.4.3 Nonmetals

6.4.3.1 General

The supplier/manufacturer's documented specifications for nonmetallic materials shall include handling, storage, and labeling requirements and define the quality control limits of characteristics necessary for the performance of the material.

This section does not cover electronic or electrical components. These components are covered in Annex F.

6.4.3.2 Elastomers

The material specifications for elastomers shall include the following, unless not appropriate for the material:

a) compound identification;

b) mechanical properties, as a minimum:

   1) tensile strength (at break),

   2) elongation (at break),

   3) durometer hardness;

c) compression set as applicable and as required;

d) tensile modulus (as applicable);

e) documentation of cure date, batch number, and shelf life appropriate to each elastomeric component;

f) storage, handling, and packaging requirements as required by the material and component;

g) other requirements necessary for the specific material and application.

6.4.3.3 Plastics

The material specifications for plastics shall include the following:

a) material identification with sufficient substantive detail to ensure repetitive tool performance within specified limits;

b) mechanical properties as required such as ultimate tensile strength, flexural modulus and hardness, and glass transition temperature;

c) requirements for documentation appropriate to each plastic component.

6.4.3.4 Ceramics

The material specifications for ceramics shall include the following:

a) material identification with sufficient detail to ensure repetitive tool performance within specified limits;

b) mechanical properties as required;

c) requirements for documentation appropriate to each ceramic component.

6.4.3.5 Other Materials

The material specifications for other materials such as fluids and lubricants shall include the following:

a) material identification;

b) properties as required;

c) requirements for documentation appropriate to each material.

6.4.4 Coatings, Platings, and Overlays

The suitability of the coatings, plating, and overlays identified for the functional requirements and component materials shall be verified and documented by a qualified person. The coating material and application process shall have a documented specification. The application process shall contain the parameters required to ensure the desired performance of the coating. Coatings, platings, and overlays shall be applied in accordance with documented procedures by qualified personnel. Acceptance tests to ensure repeated quality shall be specified and the results of each batch documented.

6.4.5 Surface Treatments

Surface treatment processes shall have a documented and approved specification by a supplier/ manufacturer qualified person, containing the parameters required to ensure the desired surface properties. Surface treatments shall be applied in accordance with documented procedures by a qualified person with acceptance criteria.

Suitability of surface treatments used to achieve the functional requirements shall be verified and documented by a qualified person. The following shall be considered when selecting an appropriate surface treatment process:

a) effect of the process on the properties of the base metal;

b) resulting surface finish and the requirements for any post-hardening processes such as grinding, polishing, honing;

c) case depth;

d) case hardness;

e) base metal preparation;

f) masking (to limit the area treated);

g) change in corrosion properties.

6.5 Design Documentation

Documentation of designs for each size, type, and model shall include:

a) functional requirements;

b) technical specifications;

c) design verifications, including methods and assumptions;

d) comparison with previous designs (where applicable);

e) design calculations;

f) design reviews;

g) factory acceptance and validation testing procedures.

Design documentation and validation results shall be retained per 7.2.1 and include the materials as defined in 7.2.2.

6.6 Design Verification

Design verification shall be performed to ensure that each design meets the technical specifications. Design verification shall include design reviews that are approved by a qualified person and may include design calculations, physical tests, comparison with similar designs, and historical records of defined operating conditions of similar tools.

6.7 Design Validation

6.7.1 General

The downhole well test tool designs produced in accordance with this specification shall have passed the validation test at the tool's rating as required in the technical specification and specified in Annex A to qualify each size, type, and model. Successful completion of the validation test and approval by a qualified person shall qualify the design for manufacture of additional tools of the same size, type, and model as the tested design.

Fluids used for pressure testing to validation level V2/V2-TP shall be water, with or without additives, or hydraulic oil/heat transfer fluid. The test fluid shall be visibly free from particulate matter and/or other material that have the potential of plugging small leaks. V1/V1-TP testing is performed with nitrogen or other inert gas. All fluids used in the testing shall be defined and documented in the test report.

Electronic and electrical components, subcomponents, and systems shall conform to Annex F.

Well test packers shall conform to Annex E.

TSSVs shall conform to Annex G.

NOTE The design validation requirements in this specification may not be representative of well conditions.

6.7.2 Supplier/Manufacturer Requirements

The downhole well test tool shall be function/pressure tested prior to validation testing. The supplier/manufacturer shall provide a tool of each size, type, and model to the validation test facility. A detailed validation test procedure that conforms to the requirements of this specification shall also be provided for each tool.

Pre-validation and post-validation testing dimensional inspections of critical dimensions defined by the supplier/manufacturer shall be conducted and documented. For a successful test, all results shall be within the established acceptance criteria, approved by a qualified person(s), and maintained in the design documentation.

6.8 Performance Envelope

A performance rating envelope as defined in Annex D shall be prepared for each validated design.

6.9 Special Feature Validation

Special features shall be validated by testing to their rated limits. Special feature validation testing shall be the responsibility of the supplier/manufacturer.

For a successful test, all results shall be within the established acceptance criteria, approved by a qualified person(s), and maintained in the design documentation.

6.10 Design Changes

6.10.1 General

Design changes shall be documented, reviewed, and approved by a qualified person(s) before implementation. Design changes and changes to design documents shall require the same controls as those applied to the design that has passed the applicable verification and validation requirements of this specification.

Design changes shall be reviewed by a qualified person of the supplier/manufacturer against the design verification and validation documents to determine if the change is a substantive change. Evaluation of design changes may include activities such as subassembly testing, analysis, and design reviews.

A design that undergoes a substantive change becomes a new design requiring design verification and design validation; however, derating is allowed per 6.10.2. All tools containing a substantive change(s) shall continue to meet applicable verification and validation test requirements.

The use of alternate seal compounds and their validation requirements shall conform to A.3.6.6 and E.7, as applicable.

The supplier/manufacturer shall, as a minimum, consider the following for each design change:

a) stress levels of the modified or changed components compared to those of the base design;

b) possible functional or operational changes introduced by the design change;

c) interchangeability with existing components or previously manufactured assemblies.

Design changes shall be communicated to the service center as applicable.

6.10.2 Derating Requirements

6.10.2.1 General

Derating of a successfully validated downhole well test tool (base design) of the same nominal size, type, and model is permitted when the requirements of this subsection and this specification are satisfied. Any increases in validated ratings shall require validation testing in accordance with 6.7.

Tool design or other changes associated with derating are limited to changes in material that result in a decrease in load, pressure, or temperature rating. Any design changes shall conform to 6.10.1.

Derated loads, pressures, or temperatures shall remain within the applicable validated range of the base design.

Each derated tool requires design verification, justification, and design documentation of the changes from the base design. Derated designs shall be approved by a qualified person, other than the person who performed the derating of the design. The documentation shall be maintained per 6.5 and included in the new tool's design records.

6.10.2.2 Derating Process

The supplier/manufacturer shall establish the maximum stresses in the derated design. The same method of calculation(s) and verification(s) shall be applied to the identified components of the base design and the derated design. For each component, the ratio of maximum stress to the yield stress shall not exceed the ratio of maximum stress to yield stress of the base design. The supplier/manufacturer shall ensure that the derated design conforms to the applicable technical specifications.

7 Supplier/Manufacturer Requirements

7.1 General

This section contains the detailed supplier/manufacturer requirements for each tool manufactured under this specification to conform to the technical specifications. These include requirements for documentation, tool identification, quality requirements, traceability, materials, additional processes, assembly and factory acceptance testing (FAT), manufacturing nonconformities, and subsupplier quality controls.

Annex B provides requirements on post-manufacture FAT.

Annex C provides the requirements for the post-manufacture processing of these tools at service centers.

7.2 Documentation

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 legible and maintained to demonstrate conformance to specified requirements. All documents and data shall be retained in facilities that provide an environment that is designed to prevent damage, deterioration, and loss. Documents and data may be in the form of any type of media, such as hard copy or electronic media. All documents and data shall be available for review and/or audit by a user/purchaser within 30 days of the request.

Documentation shall be retained for a minimum of 3 years after a tool has been obsoleted.

Service center documentation requirements are included in Annex C.

7.2.2 Retained Documentation

7.2.2.1 Documentation Requirements for a V1/V1-TP and V2/V2-TP Validated Design

The supplier/manufacturer shall have the following information available to support each design validated for level V1/V1-TP and V2/V2-TP:

a) technical specifications and design requirements, which include pressures, operational loads, materials, environmental and other pertinent requirements upon which the design is based;

b) engineering drawings/bills of material/manufacturing specifications/revision history;

c) material specifications;

d) assembly drawings;

e) nonconformance documentation;

f) design verifications, including methods and assumptions;

g) comparison with previous designs (where applicable);

h) design calculations;

i) design reviews;

j) validation testing procedures and acceptance criteria;

k) validation results/report;

l) performance envelope;

m) certificates of conformance;

n) material test reports (MTRs);

o) heat treat certificates;

p) material traceability records;

q) dimensional inspection records;

r) NDE records;

s) FAT procedures and records;

t) shear/burst device testing records (where applicable);

u) welding procedures/NDE inspections (where applicable);

v) special feature validation results (where applicable).

7.2.2.2 Documentation Requirements for a V3/V3-TP Validated Design

The documentation requirements for V3/V3-TP validated designs are included in A.3.5 and E.4.

7.2.2.3 Documentation Requirements for Manufactured Tools

The supplier/manufacturer shall have the following information (as of the date of manufacture) available to support each manufactured tool:

a) engineering drawings/bills of material (as built);

b) assembly drawings;

c) nonconformance documentation;

d) operating/maintenance manual;

e) performance envelope;

f) certificates of conformance (where applicable);

g) subcomponent test reports (where applicable);

h) MTRs;

i) heat treat certificates;

j) material traceability records;

k) dimensional inspection records;

l) NDE records;

m) FAT records;

n) shear/burst device testing records (where applicable);

o) welding procedures and associated NDE inspections (where applicable).

7.2.2.4 Documentation Requirements for Service Center

The supplier/manufacturer shall have the following information available to support each tool supplied to the service center:

a) datasheet, technical specifications;

b) bills of material;

c) assembly drawings;

d) operating and maintenance manual;

e) performance envelope;

f) certificates of conformance;

g) MTRs;

h) heat treat certificates (where applicable);

i) material traceability records;

j) NDE records;

k) supplier/manufacturer's functional testing records;

l) summary design validation report(s);

m) shear device testing records (where applicable).

7.2.2.5 Operating and Maintenance Manual(s)

For each manufactured downhole well test tool, the following information, as applicable, shall be available in the appropriate manual(s):

a) methods for safe assembly and disassembly;

b) recommended field use and operating instructions for the tool;

c) tool hazard(s)/safety identifications;

d) contact information of supplier/manufacturer;

e) supplier/manufacturer assembly number and tool name;

f) size, type, and model;

g) design validation grade;

h) operational ratings and limits, including:

   1) differential pressure (internal and external) at minimum and maximum rated temperatures;

   2) absolute pressures (internal and external) at minimum and maximum rated temperatures;

   3) other pressure restrictions, static/dynamic;

   4) operating temperature range, including any known temperature exposure limitations;

   5) tensile and compressive capacity at minimum and maximum rated temperatures (as applicable and including tool end connections);

   6) operational cycle limits;

   7) rated operating envelope as applicable by validation grade;

   8) where applicable, a table shall be supplied that establishes ratings with the validated design and material variations and the tool's capabilities within those variations—examples of contents of these tables include packer element durometer/compound, gauge ring OD, and sealing system variations;

i) type, size, and weight of tool end connections, where applicable;

j) tool dimensions, including minimum ID, maximum OD, makeup length, and dimensional data needed for inspection/operations;

k) operational information, such as pre-charge pressures, activation pressures, shear pressures, and activation loads;

l) requirements for related tool(s);

m) drawings and illustrations of the fully assembled tool, including a dimensional drawing for fishing purposes;

n) bill of material and any special tool requirements;

o) special feature operational procedures;

p) troubleshooting procedures;

q) repair procedures/limitations for Levels 1, 2, and 3 (see C.6.2, C.6.3, and C.6.4);

r) redress procedures/limitations;

s) preparations for shipment requirements;

t) storage requirements.

7.2.2.6 Datasheet Requirements

7.2.2.6.1 General

The supplier/manufacturer shall have available, at the time of tool delivery to the service center, a datasheet that details the tool's operating capabilities. Multiple sizes of the same tool type can be included on the same datasheet. Each rating shall be identified as either validated or verified as required in this specification.

The well test tool's datasheet shall include:

a) validation grade (V3, V2, V1);

b) nominal tool size, such as OD, ID, and length;

c) tensile rating including tool end connections;

d) compressive rating including tool end connections (straight compression without bending or buckling);

e) maximum absolute internal (bore) pressure;

f) maximum absolute external pressure;

g) maximum differential pressure(s) inside to outside and outside to inside;

h) other pressure restrictions applicable to the tool such as differential pressure across a closure mechanism (from below, above, inside, outside);

i) operational temperature range(s), including temperature drop from rated maximum temperature or sets of temperature drops from specific temperatures;

j) operational cycles per job;

k) minimum operational temperature rating;

l) minimum exposure temperature (ability to maintain integrity at low subsea temperatures);

m) pressure testing limits at low temperature (rated pressures at low temperature);

n) low temperature limit at which function testing can be performed;

o) pressure drop at a defined flow rate(s) at ambient temperature with water on ported tools;

p) service rating for H_2S and CO_2;

q) other operational/environmental capabilities and limitations as applicable.

The test tool's datasheet shall clearly distinguish between validated and verified absolute pressure ratings.

A performance rating envelope is a separate document (per 6.8).

7.2.2.6.2 Packer Datasheets

The supplier/manufacturer shall have available, at the time of tool delivery to the service center, a datasheet that details the well testing packer operating capabilities. Any associated tool operational restrictions shall be fully documented in the tool's datasheet and documentation.

The packer's datasheet shall include the following data and ratings:

a) validation grade (V3-TP, V2-TP, V1-TP);

b) nominal tool size, such as OD, ID, and length;

c) applicable casing size and weight(s);

d) tensile rating, including packer end connections;

e) compressive rating, including packer end connections (straight compression without bending or buckling);

f) tensile/compressive ratings of slip/anchoring systems in the hardest rated casing grade;

g) absolute internal (bore) pressure;

h) absolute external (annulus) pressure;

i) differential pressure (bore to annulus);

j) differential pressure across packer body (plugged condition);

k) differential pressure across element from above and below (with minimum setting load/pressure);

l) other pressure restrictions applicable to the packer;

m) operational temperature range(s), including a temperature drop from rated maximum temperature or sets of temperature drops from specific temperatures;

n) number of operational sets per job;

o) minimum operating temperature of the packer;

p) minimum exposure temperature (ability to maintain integrity at low subsea temperatures);

q) pressure testing limits at low temperature;

r) service rating for H_2S and CO_2;

s) other operational/environmental capabilities and limitations as applicable.

The test tool's datasheet shall clearly distinguish between validated and verified absolute pressure ratings.

A performance rating envelope is a separate document (per 6.8).

7.2.2.6.3 TSSV Datasheets

The supplier/manufacturer shall have datasheets that detail the TSSV operating capabilities. Any associated tool operational restrictions shall be fully documented in the tool's datasheet and documentation.

The tool's datasheet shall include:

a) maximum operating temperature;

b) minimum temperature (if rated to less than ambient);

c) internal rated working pressure at maximum rated temperature (burst direction);

d) external rated working pressure at maximum rated temperature (collapse direction);

e) differential across the closure from below at maximum rated temperature;

f) pressure rating of operating chamber at maximum rated temperature (if less than the internal rated working pressure);

g) integrity test pressure (1.5 times working pressure at ambient temperature);

h) pump-through rate (with valve closed);

i) chemical injection rate;

j) rated collapse/external pressure during closure function;

k) ported slick joint collapse rating;

l) valve closure time;

m) cutting capabilities;

n) other operational/environmental capabilities and limitations as applicable.

The following capabilities shall be validated or verified:

a) tensile rating at 0 psi;

b) tensile rating at rated working pressure and ambient temperature (calculated);

c) tensile rating at rated working pressure and maximum rated temperature (calculated);

d) service rating for H_2S and CO_2.

The test tool's datasheet shall clearly distinguish between validated and verified absolute pressure ratings.

A performance rating envelope is a separate document (per 6.8).

7.3 Product Identification

Tools furnished to this specification shall be permanently identified in accordance with the supplier/manufacturer's documented specifications. The supplier/manufacturer's specifications shall define the type, method of application, and location of the identifications. The identifications shall include the following:

a) manufacturer's part number, including revision level;

b) unique identifying serial number and/or trace number.

7.4 Quality Level

A single level of quality control requirements is specified for all tools and components manufactured under this specification. These requirements are summarized in Table 2 and detailed in referenced Section 7.5 through Section 8.

7.5 Quality Controls

7.5.1 Measuring/Testing Equipment Calibration

The supplier/manufacturer shall establish and implement requirements for all quality processes used on measuring/testing equipment conforming to this specification and shall be approved by a qualified person(s).

Inspection, measuring, and testing equipment used for acceptance shall be used only within its calibrated range and shall be identified, controlled, calibrated, and adjusted at specific intervals in accordance with the supplier/manufacturer requirements, not to exceed 1 year.

All measuring and test equipment shall be calibrated to an approved standard, which shall ultimately be calibrated and certified to national or international standard(s) at least once every 3 years.

Table 2—Quality Requirement Summary

Topic	Requirements
Documentation	As per 7.2
Product identification	As per 7.3
Nonmetals	As per 6.4.3 and 7.9
Heat treatment	As per 7.11
Coatings, plating, and overlays	As per 7.5.2.11
Surface treatments	As per 7.5.2.12
Component traceability	As per 7.8
Welding and brazing	NDE as per 7.5.2.3
Assembly serialization	As per 7.8.2
Hardness	As per 7.5.2.6
Component NDE	As per 7.5.2
Component dimensions and threads	As per 7.5.2.13 and 7.5.2.14
Visual inspection	As per 7.5.2.15
Shear and rupture devices	Lot validation per 7.6 and 7.7
Assembly verification	Functional test per 7.13
NOTE 7.2 applies to all parts of Section 7 listed.	

7.5.2 NDEs

7.5.2.1 General Requirements

As appropriate, NDE per 7.5.2.7, 7.5.2.8, 7.5.2.9, and 7.5.2.10 shall be conducted on load-bearing/pressure-retaining metallic components and threads according to the manufacturer's documented specifications that include acceptance criteria and the requirements of this section.

All NDE instructions shall be approved by a qualified NDE Level III examiner as per a national or international standard such as ISO 9712 or ASNT SNT-TC-1A. Visual examination requirements do not require Level III approval. Acceptance of all materials/documents shall be permanently indicated either on the materials/documents or in records traceable to them.

7.5.2.2 NDE Personnel Qualifications

All personnel performing inspections for acceptance shall be qualified in accordance with the supplier/manufacturer's documented requirements.

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

Personnel performing NDE evaluation/interpretation shall be qualified in accordance with ISO 9712 to a minimum of Level II or equivalent such as defined in ASNT SNT-TC-1A.

7.5.2.3 Welding and Brazing

Welds, brazes, and adjacent heat-affected zones shall be nondestructively examined by one or more of the following methods: radiography, magnetic particle, ultrasonic, or liquid penetrant as designated in the supplier/manufacturer’s specifications. This section does not apply to nonstructural components as determined by a supplier/manufacturer’s qualified person.

7.5.2.4 Castings and Forgings

Load-bearing and/or pressure-retaining castings and forgings shall be magnetic particle or liquid penetrant inspected for surface defects and shall be volumetrically inspected by radiographic or ultrasonic techniques to verify conformance with the supplier/manufacturer’s specifications.

7.5.2.5 Indications

Any unacceptable indications shall be removed or repaired according to the supplier/manufacturer’s procedures and reexamined using the original NDE method and acceptance criteria.

7.5.2.6 Hardness Testing

All load-bearing/pressure-retaining metallic components shall be hardness tested as per supplier/manufacturer approved procedures.

Hardness testing on metallic components shall, as a minimum, be 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.

Hardness conversion to other measurement units can be in accordance with ISO 18265 or a supplier/manufacturer’s documented hardness conversion based on actual measurements for a particular alloy.

NOTE For the purposes of this standard, ASTM E140 is equivalent to ISO 18265.

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.

7.5.2.7 Liquid Penetrant Inspections

When required by the supplier/manufacturer or this specification, liquid penetrant inspection shall be conducted in accordance with a national or international standard such as ASTM E165/E165M to 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).

7.5.2.8 Wet Magnetic Particle Inspections

When required by the supplier/manufacturer or this specification, wet magnetic particle inspections shall be in accordance with a national or international standard such as ISO 13665 or ASTM E709. The minimum acceptance criteria are defined in 7.5.2.7.

7.5.2.9 Ultrasonic Inspection

When required by the supplier/manufacturer or this specification, ultrasonic inspections shall meet the requirements of an international or national standard such as ASTM E428 and ASTM A388//A388M. Acceptance criteria shall be per an international or national standard such as ASTM A609 or alternatively per documented criteria specified by the supplier/manufacturer.

7.5.2.10 Radiographic Inspection

When required by the supplier/manufacturer or this specification, radiographic NDE inspections shall meet the requirements of a national or international standard such as ASTM E94. Acceptance criteria shall be per an international or national standard or alternatively per documented criteria specified by the supplier/manufacturer.

7.5.2.11 Coatings, Platings, and Overlays

Coatings, platings, and overlays shall be inspected in accordance with documented instructions that include acceptance criteria approved by a qualified person(s). A certificate of conformance (COC) stating that the process meets the manufacturer's requirements for the applicable components shall be provided.

7.5.2.12 Surface Treatments

Surface treatments shall be inspected in accordance with documented instructions that include acceptance criteria approved by a qualified person(s). A COC stating that the process meets the manufacturer's requirements for the applicable components shall be provided.

7.5.2.13 Component Dimensional Inspection

Components except common hardware shall be dimensionally inspected according to 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.

Dimensional tolerances of O-rings shall be in accordance with standards such as ISO 3601-1 or as per manufacturer/supplier's specifications if not covered by any industry standard. Other sealing elements shall meet dimensional tolerances of the supplier/manufacturer's documented specifications.

7.5.2.14 Thread Inspections

Threads, except those of common hardware, shall be inspected to the tolerances, inspection requirements, gauges, gauging practices, gauge calibration, and gauge certification to conform to the specified thread design owner's specifications.

7.5.2.15 Visual Inspection

Components shall be visually inspected according to the supplier/manufacturer's documented procedures, including acceptance criteria, by a qualified person(s) to ensure all accessible surfaces are free from defects, debris, and damage prior to assembly.

Visual inspection of O-rings shall be in accordance with ISO 3601-3 or equivalent. Other sealing elements shall be visually inspected in accordance with the supplier/manufacturer's documented specifications.

7.6 Shear Device Validation

A shear device validation shall be performed per manufactured batch by a qualified person(s) to meet the specified shearing load range(s) in accordance with the supplier/manufacturer's documented procedure and acceptance criteria.

7.7 Rupture Disc Validation

A rupture disc validation shall be performed per manufactured batch by a qualified person(s) to establish the specified pressure rating in its intended direction in accordance with the supplier/manufacturer's documented procedure and acceptance criteria. General guidance on rupture disc processing controls can be found in ISO 4126-2.

7.8 Traceability

7.8.1 General

All load-bearing/pressure-retaining components and other components designated by the manufacturer/supplier shall be traceable in accordance with the supplier/manufacturer's documented procedures to an MTR from the heat lot, batch lot, or component-specific testing and evaluation of raw material.

Traceability for tools and components manufactured to this standard shall be provided to service centers in accordance with C.8.2 and retained in accordance with 7.2.

7.8.2 Serialization and Traceable Component Recording

Tools shall be serialized with a permanently applied unique identifier. All load-bearing/pressure-retaining components and other components designated by the manufacturer/supplier shall be traceable.

Components within an assembly may be serialized; however, at a minimum they shall be traceable to the manufactured batch and revision level. Traceable components without serialization or batch marking due to dimensional or technical limitations shall be recorded in the unique manufacturing documentation for that tool at the time of assembly.

Common hardware and other nontraceable parts are exempted from this requirement.

7.9 Materials Documentation

Each heat and/or job lot or batch of material used in the manufacture of load-bearing/pressure-retaining components and other components designated by the manufacturer/supplier shall require the following documents:

a) COC stating that the material meets the manufacturer's documented specifications (see 6.4.1);

b) MTR that the manufacturer shall use to verify that the material conforms to the manufacturer's material specifications (see 6.4.1).

7.10 Subsupplier Qualifications

The supplier/manufacturer shall purchase components and services integral to the downhole test tools only from approved subsuppliers that are included within a documented approved supplier's quality monitoring program. A documented evaluation procedure and acceptance criteria shall be implemented on a repeatable basis to ensure that each subsupplier's products/services conform to the supplier/manufacturer's specifications. Exceptions to this requirement include common hardware and other nontraceable components.

7.11 Heat Treatment

Heat treatment of raw material and production parts shall be performed according to documented procedures, utilizing heat treating equipment that has been calibrated and surveyed by qualified person(s).

If heat treatment is performed by a subcontractor, the subcontractor shall provide a COC to the supplier/manufacturer stating that the heat treatment meets the supplier/manufacturer's documented specifications. If heat treatment is performed by the supplier/manufacturer, heat treatment shall comply with the supplier/manufacturer's documented specifications.

Each heat in a batch of material that is heat treated shall be tested for conformance to each of the mechanical properties specified by the supplier/manufacturer.

7.12 Additional Processes

When processes are used on tools or components that are not defined and not validated by subsequent monitoring or measurement defined elsewhere in this standard, the supplier/manufacturer shall establish applicable specifications. These specifications shall include topics such as physical and chemical properties, procedures, inspection methods and acceptance criteria. These specifications shall be prepared and approved by a qualified person(s). The supplier/manufacturer shall validate conformance to these additional process specifications.

7.13 Assembly and Functional Test

The following are necessary for proper assembly and functional testing.

a) The supplier/manufacturer shall have procedures for correct assembly of each tool. The procedures shall be approved by a qualified person other than the person who created the procedure.

b) Each tool shall be assembled by a qualified person(s). The assembly processes and activities shall conform to the defined procedures.

c) Each tool shall be functionally tested to the requirements and acceptance criteria as defined in Annex B. Testing shall be discontinued if the tool fails to perform within the limits specified for any step, except when such failures are determined to be a result of a failure within the test facility that does not affect the validity of the test as determined and approved by a qualified person(s).

7.14 Disposition of Manufacturing Nonconformities

The supplier/manufacturer 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 the identification, documentation, evaluation, segregation (when applicable), and disposition of nonconforming components or assemblies. Responsibility for review and authority for disposition of nonconforming assemblies or components shall be defined in procedures established by the supplier/manufacturer and carried out by a qualified person(s).

7.15 Correction of Manufacturing Nonconformities

The supplier/manufacturer shall establish and maintain documented procedures to facilitate correction and acceptance of nonconforming assemblies or components. A corrected component or assembly shall conform to the original design requirements. An accepted component shall conform to the supplier/manufacturer criteria, evaluated by a qualified person in conformance to a quality management system. Responsibility for review and authority for correction of nonconforming assemblies or components shall be defined in procedures established by the supplier/manufacturer and carried out by a qualified person(s).

7.16 Test Facility

Test facilities shall provide all the equipment required to achieve the testing parameters and to measure the stated acceptance parameters to an accuracy that meets or exceeds the defined requirements.

Testing shall be discontinued if the test facility fails to perform within the limits specified for any step, except when such failures or test facility anomalies do not affect the validity of the test as determined and approved by a qualified person(s).

8 Handling, Storage, and Preparation for Transport

Prior to transport, tools and components shall be handled and stored according to the documented specifications of the supplier/manufacturer to prevent deterioration/damage. Tools and components shall be packaged for transport according to the documented specifications of the supplier/manufacturer to prevent deterioration/damage during shipping. All material provided as protection for transport shall be clearly identified for removal prior to use of the tool.

Annex A
(normative)

Validation Requirements for Downhole Well Test Tools and Related Equipment

A.1 General

A.1.1 General Information

Each well test tool design provided in accordance with this specification shall conform to the requirements of this annex with the exception of well testing packers, which are covered in Annex E, and TSSVs, which are covered in Annex G. Each well test tool design shall pass all requirements within the limits specified and conform to the acceptance criteria defined, with suitable documentation of the applicable processes, acceptance criteria, and evaluation results required for design validation. The defined evaluations and testing parameters shall validate the stated performance and capabilities of the tool. All tests and tool-related data for a valid, successful test shall be recorded in a legible and retrievable manner and retained as a portion of the tool's validation records following approval by a qualified person(s).

Design validation grades V1 and V2 require specified testing (see Table A.1). Design validation grade V3 requires supplier/manufacturer-defined requirements (see A.3.5).

Each design validation grade requires one or more individual validation procedure(s), process(s), or test(s). All tested tools shall be uniquely identified and shall conform to the requirements of Sections 5, 6, and 7. The test procedures and detailed testing results shall be included in the record of that tool design documentation. The validation records shall contain test results and/or calculations that validate the design. The validation records shall be reviewed and approved by a qualified person other than the originator. This review shall verify that, as a minimum, all of the requirements of this annex of this specification have been met.

Test facility anomalies occurring during testing that have no effect on tool testing performance may be accepted when documented and approved by a qualified person(s). Each design validation report shall be signed and dated by the qualified person(s) conducting and approving the test results. The design validation report content is specified in A.3.6.5. Any associated tool operational restrictions shall be fully documented in the tool's datasheet and documentation.

A.1.2 Test Facility

Validation test facilities shall provide all the equipment required to achieve the defined testing parameters and to measure the stated acceptance parameters to an accuracy that meets or exceeds the defined requirements. All fluids used in the assembly and testing shall be defined and documented in the test report.

Pressure and temperature testing hardware, facilities, procedures, and practices shall conform to all applicable regulations and requirements, including a quality management system. All validation testing procedures shall be documented and shall contain the approval of a qualified person. Testing shall be performed by qualified persons. Test facilities and tools shall have current records of calibration within the specified range of use.

A.2 Assembly Evaluation Requirements

The assembly processing shall follow the supplier/manufacturer's documented procedures, including fluids, lubricants, and methods. Any variance from the requirements shall be documented and corrected prior to initiating the testing process.

Components of the tested tool shall be traceable to their unique materials and processing and visually inspected per 7.5.2.13 and 7.5.2.15 by a qualified person(s) prior to tool assembly. Pre-validation and post-validation testing dimensional inspections of critical dimensions defined by the supplier/manufacturer shall be conducted and documented to allow comparative inspection after validation testing. For a successful test, all results shall be within the established acceptance criteria, approved by a qualified person(s), and maintained in the design documentation.

A.3 Design Validation

A.3.1 General

The supplier/manufacturer shall document all parameters and results of the evaluations to demonstrate conformance to the validation grade. The supplier/manufacturer shall have documented testing procedures for performance of the defined testing steps. A single tool assembly (as shown in Table A.1) shall successfully perform all of the defined test steps of each set of validation tests for the appropriate validation grade level. The tool assembly may be redressed for any special feature testing; however, repair or redress during a contiguous testing sequence requires the testing to restart at the beginning.

For test tools containing a unique combination of features not shown in Table A.1, validation testing described in this annex shall be utilized and conformed to as much as practical by the tool design. The base validation shall be selected from the testing procedures shown in Table A.1 and the applicable additions or subtractions necessary to facilitate effective testing of that product design. The procedure changes shall be justified and approved by a qualified person other than the preparer and approved by a person qualified to perform the testing. All acceptance criteria, recordkeeping, and record retention requirements also apply.

The testing parameters shall include the following.

a) The tool shall be assembled and installed into the test facility, utilizing supplier/manufacturer documented procedures.

b) All testing shall be performed in the order prescribed, to the limits defined, on calibrated equipment per 7.5.1, by qualified personnel, and all testing results and commentary shall become a portion of the tool's design documentation.

c) The testing steps represented in A.3.6 shall be conducted over a minimum of 5 days at the specified elevated temperature, exclusive of initial heating and final cooldown.

d) The supplier/manufacturer shall have a procedure to establish when pressure and temperature are sufficiently stabilized. This variation of stabilized pressure, as prescribed by these criteria, shall conform to the pressure integrity acceptance criteria in A.3.2.2.

e) All applied temperatures, pressures, loads, and actions shall be measured and recorded on time-based equipment.

f) The tool shall be operated to the number of operational cycles claimed by the supplier/manufacturer during the validation profile test sequence. Additional time may be added to the validation profile test sequence to accomplish tool validation as specified in A.3.6.

g) During temperature transitions, pressure shall be managed in accordance with supplier/manufacturer facility capabilities. Prescribed pressure and temperature conditions shall be stabilized before prescribed hold periods. Prescribed conditions (pressure and/or temperature) shall continue until a change in those conditions is specified by a subsequent test step.

h) For tools using a rupture disc or shear device to function the tool, and where it is not possible to achieve maximum test pressures required for validation testing without exceeding the rupture or shear device value, it is permissible to perform a separate test to validate the maximum pressure ratings with activation method disabled.

i) Alternative test methods may include using a control line or installing a blank rupture disc to validate the maximum rated pressure of the tool. This additional test shall be performed at the tool's maximum rated temperature, but the test does not require repeating the full validation profile test sequence. A qualified person shall document the justification for utilizing the alternate test method, procedures, and acceptance criteria.

j) The design validation of nonmetallic element(s) at higher absolute pressure shall include subassembly or laboratory testing or be supported by successful V2 validation of the same nonmetallic compound at the higher absolute pressure on other tool assemblies having the same seal design. For subassembly testing of seals, the provisions of A.3.6.6 shall apply.

k) Any low temperature performance rating not tested during the validation profile test sequence in A.3.4 shall be established through separate testing. Such testing and results shall conform to the supplier/manufacturer's documented procedures and acceptance criteria. Such rating limits may include, but are not limited to, pressure testing limits at low temperature, function testing at low temperature, or the ability to maintain integrity at low subsea temperatures while running in hole (RIH).

l) For special features, see A.3.2.4.

Annex A design validation testing is divided into the following three categories: nonclosure tools, single-cycle tools, and multi-cycle tools.

A.3.2 Design Validation Testing Acceptance Criteria

A.3.2.1 General

The acceptance criteria in this section shall apply to all pressure integrity testing, including closure mechanism. Each tool design shall conform to the requirements and acceptance criteria at each numbered test step. Failure to conform to the requirements is cause to stop the testing and restart from the beginning of the validation testing process.

A.3.2.2 Pressure Integrity Tests

A.3.2.2.1 General

Pressure integrity tests are to be performed with liquid for V2 validation followed by gas for V1. Any visible leakage, internally or externally, is cause for test failure.

A.3.2.2.2 Pressure Tests with Liquid

For V2 validation, testing is performed with a liquid. Each tool shall be pressure tested at the defined pressure(s) and associated defined temperature(s) using supplier/manufacturer's procedures. Test medium shall be water, with or without additives, hydraulic oil, or heat transfer fluid. Liquid shall be visibly free from particulate matter and/or other material that have the potential of plugging small leaks.

In this specification, leakage is considered to be a measureable change in pressure over time. The pressure test acceptance criteria is a maximum of 1 % change in the applied pressure, with a decreasing rate of change, over a period of 15 minutes after sufficient time has been allowed for stabilization.

A.3.2.2.3 Pressure Tests with Gas

For V1 validation, testing is performed with nitrogen or other inert gas. Testing can be performed as a continuation of the V2 test profile with the tool still at maximum rated temperature in the test fixture or as a standalone test performed on a newly redressed tool at its maximum rated temperature. Filler bars may be used to minimize gas volume. As an alternative to testing at the tool assembly level, a seal design may be tested in gas at the maximum rated temperature at a subassembly level, provided that the test fixture replicates the tool design, loading, and functionality.

Gas leak rate acceptance criteria is less than 20 cm^3 of gas at atmospheric pressure over a 15-minute hold period after sufficient time has been allowed for stabilization after applying the rated differential pressure. Additionally, the volume accumulated during the second $7^1/2$ minutes of the hold period shall not exceed the volume accumulated in the first $7^1/2$ minutes of the hold period. The leak rate and total leakage shall be recorded in the test report.

A.3.2.2.4 Pressure-retaining Chamber Tests

Each tool that includes a pressure-retaining chamber (such as a hydraulic or gas chamber used in the operation of the tool and/or other similar pressure-retaining chamber) that is not tested during the validation or functional tests shall be pressure tested by a qualified person(s). If this chamber is not tested during the validation or functional tests, it must be tested at the maximum rated internal pressure of the chamber at room temperature using the supplier/manufacturer's procedures and acceptance criteria.

A.3.2.3 Function Test(s)

Each tool shall be tested to open/close or function through its operational cycle(s) at specified temperature(s) in accordance with the supplier/manufacturer's procedures. This shall include the number of cycles, required signals (including its parameters) and loads applied shall conform to the number of cycles claimed for operational durability. Acceptance criteria requires conformance to the supplier/manufacturer's documented requirements.

A.3.2.4 Special Features Test(s)

Special feature and/or claimed capability(s) shall be tested in accordance with the supplier/manufacturer's documented test procedures. These tests may be inserted into the validation test profile provided the special feature tests do not interfere with the performance of the prescribed profile steps. Any special feature testing that may interfere with the performance of the prescribed profile steps shall be performed in a separate test. Results shall conform to the supplier/manufacturer's documented acceptance criteria.

A.3.2.5 Drifting Requirements and Acceptance Criteria

After all functional testing steps are complete, perform a drift test using a drift bar having a minimum length of 42 in. (±0.5 in.) at the specified diameter. The drift bar shall have a diameter no less than the nominal tool inner diameter minus 0.125 in. inclusive of diametral and straightness tolerances. The drift bar shall pass completely through the tool in both directions where feasible, and it shall not require a force greater than the weight of the bar. Each drift bar shall be permanently marked with a unique identifier and the measured drift bar dimensions. The drift bar unique identifier shall be recorded in the validation test report.

A.3.3 Overview of Design Validation

Table A.1 presents a summary of the testing to be performed for each validation grade and tool type. For V1 and V2 validation grades, the tests are performed in the order outlined in the validation profile test sequence (see A.3.6). The performance of the entire sequence is required for an acceptable test.

A.3.4 Overview of Validation Profile Test Sequence

Figure A.1 is a graphical illustration of common well test conditions that are typically expected during well test operations. The specific validation profile test sequence requirements are defined in A.3.6 for each tool type.

The validation profile test sequence includes temperature, pressure, and time. Tools used in a specific well test may not be subjected to each of the maximum conditions indicated in a single well test; however, this specification requires the tool design to be validated to that tool's rated capability. Key pressure points are illustrated by labels 1 to 12 in Figure A.1.

Table A.1—Validation Testing Coverage by Tool Type and Grade

<table>
<tr><th colspan="4">Summary of the Testing for Each Validation Grade and Tool Type</th></tr>
<tr><td>Tests</td><td>A.3.6.2 procedures</td><td>A.3.6.3 procedures</td><td>A.3.6.4 procedures</td></tr>
<tr><td>Type</td><td>Nonclosure tools</td><td>Single-cycle tools</td><td>Multi-cycle tools</td></tr>
<tr><td>Tools to be validated</td><td>— Safety joint
— Slip joint
— Jar
— Sampler carrier
— Gauge carrier
— Drain valve</td><td>— Tester valve—single cycle
— Circulating valve—single cycle
— Safety valve—pump-through
— Safety valve—non-pump-through
— Work string tester valve</td><td>— Tester valve—multi-cycle
— Circulating valve—multi-cycle</td></tr>
<tr><td>V3</td><td colspan="3">Supplier/manufacturer-defined requirements (A.3.5)</td></tr>
<tr><td rowspan="10">V2</td><td colspan="3">Tool is subjected to a prescribed pressure/temperature event sequence lasting a minimum of 5 days at elevated temperature to validate the following with liquid.</td></tr>
<tr><td colspan="3">Internal Pressure—Validation of internal to external differential pressure rating. Tested to 105 % of rated pressure at rated max temperature.</td></tr>
<tr><td colspan="3">External Pressure—Validation of external to internal differential pressure rating. Tested to 105 % of rated pressure at rated max temperature.</td></tr>
<tr><td colspan="3">Absolute Pressure—Validation of tool's absolute pressure rating. Tested to 105 % of rated pressure at rated max temperature.</td></tr>
<tr><td rowspan="2">Not applicable to nonclosure tools</td><td colspan="2">Closure Mechanism Static Pressure—Validation of the differential pressure(s) and direction(s) at which the tool's closure mechanism is rated to seal. Tested to 105 % of the rated differential pressure at rated max temperature. A closure mechanism may have different ratings, depending on the direction of applied pressure (i.e. a tester valve or circulating valve) or the closure mechanism may only be rated in a single direction (i.e. a flapper valve).</td></tr>
<tr><td colspan="2">Closure Mechanism Dynamic Opening Pressure—Validation of the differential pressure(s) and direction(s) at which the tool's closure device is rated to function open (not the pressure required to operate the valve). Tested to 105 % of the rated differential pressure at rated max temperature. A closure mechanism may have different dynamic opening ratings, depending on the direction of applied pressure.</td></tr>
<tr><td colspan="3">Cooldown Temperature (Temperature Drop)—Validation of a tool's pressure integrity and functionality after being cooled down from its maximum rated temperature such as that which would occur as the result of stimulation pumping. The maximum cooldown from max temp and the associated pressure reversal are to be included in the tool's specification.</td></tr>
<tr><td colspan="2">Not applicable to nonclosure and single-cycle tools</td><td>Operational Cycles—Validation of the tool's rated number of operational cycles.</td></tr>
<tr><td colspan="3">Drift Test—Confirmation that the ID of the tool can pass a drift bar of a prescribed diameter.</td></tr>
<tr style="display:none"><td colspan="3"></td></tr>
<tr><td rowspan="2">V1</td><td colspan="3">Validation of tool's ability to seal with gas at the internal to external pressure rating (tested to 105 % of rated pressure at rated max temperature with ends capped and no OD pressure).</td></tr>
<tr><td>Not applicable</td><td colspan="2">Static Closure Mechanism Pressure with Gas—Validation of the differential pressure(s) and direction(s) the tool's closure mechanism is rated to seal with gas as the test medium (tested to 105 % of rated pressure at rated temperature).</td></tr>
</table>

The baseline hydrostatic pressure L0 shown in Figure A.1 is a minimum hydrostatic pressure during the validation test, and it shall be no less than 50 % of the tool's absolute pressure rating. A different baseline hydrostatic pressure can be established at any point in the test provided it is never less than 50 % of the absolute rating.

Labels 1 and 2 simulate the tool's preparation and running into the well.

Label 3 is a validation of the tool's absolute pressure rating. It is very typical that the work string will be pressure tested while RIH, hence label 4 is a validation of the tool's absolute and differential ratings (internal and external) at temperature, performed two times.

Labels 5 and 6 simulate drawdown and buildup events where the annulus pressure is greater than the tool's internal pressure.

Label 7 simulates an injection event, where the tool experiences a decrease in temperature with a corresponding pressure reversal.

Label 8 simulates a screen-out, where internal tool pressure further increases. This is intended to validate the tool's capabilities to continue to function with a temperature excursion.

Labels 9 and 10 represent the final flow period.

Labels 11 and 12 indicate a simulation of end of job conditions where well kill operations could again require full differential and/or absolute pressure capabilities and valve operations in addition to the effects of pulling out of hole.

A.3.5 Supplier/Manufacturer Requirements V3

To address legacy designs, results from separate tests and/or documented field history performance may be combined to validate the tool's ratings. The supplier/manufacturer shall demonstrate and document that the validation testing results and/or documented field history meet the requirements of the tool's ratings. Ratings shall be documented and approved by a qualified person other than the qualified person who performed the testing.

Test(s) results and/or documented field history performance shall be compiled into a report that establishes the tool's performance capabilities and ratings. Test results and procedures shall be documented with an adequate amount of detail to allow the testing process to be replicated.

Design changes to V3 tools shall conform to the requirements of 6.10.

Following the effective date of this specification, new tool designs that conform to this specification shall meet the requirements of V2 or V1. Legacy designs that comply with V3 requirements of this specification may be validated to comply with V2 or V1 provided all requirements of A.3.5 are performed.

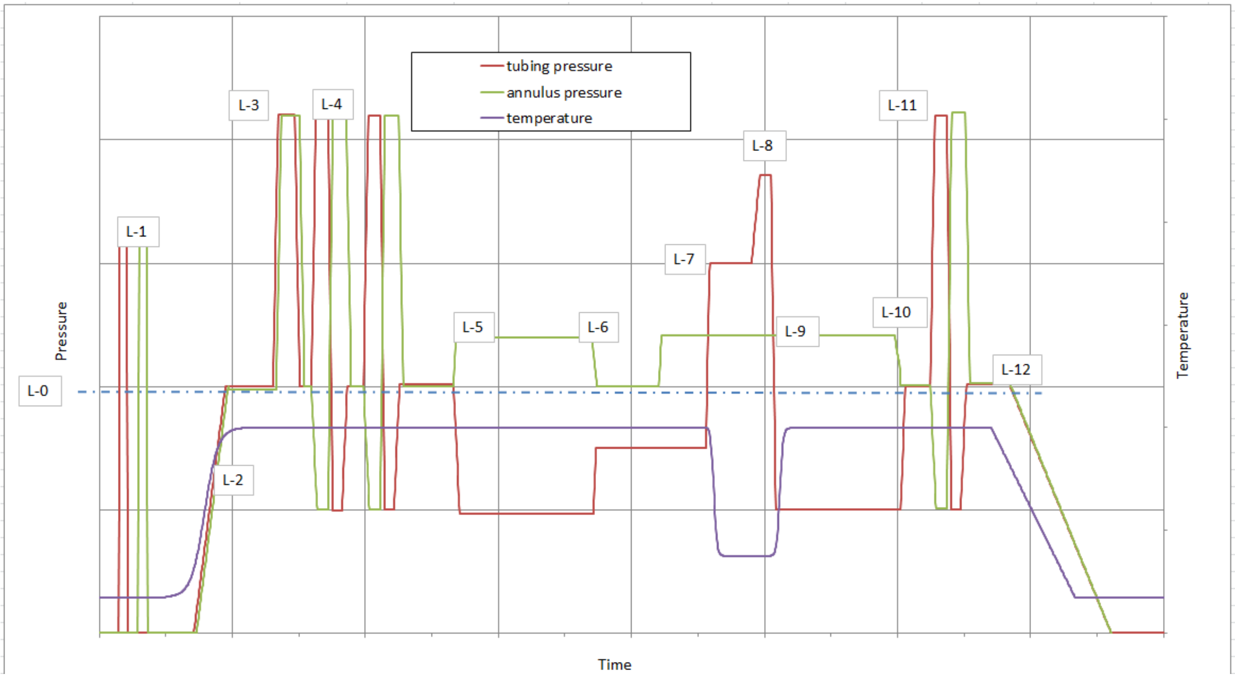
A.3.6 Supplier/Manufacturer Requirements V2 and V1

A.3.6.1 General

An absolute pressure rating shall be validated as prescribed in the validation profile test sequences in A.3.6.1 through A.3.6.4. If a separate verified absolute pressure rating (as opposed to the validated rating) is established, the verified absolute pressure rating shall conform to the requirements of 6.6. The tool's datasheet shall clearly distinguish between validated and verified absolute pressure ratings.

Prior to installation of tools into the test vessel, perform—as a minimum—drift, visual inspection, pressure integrity, and function tests per supplier/manufacturer procedures.

NOTE An example of a verified absolute pressure rating is given by a tool containing no atmospheric chambers and supplementary laboratory test data that indicate the properties of the elastomers are not adversely affected by hydrostatic pressure in the range between the validated and verified pressure.



Labels

L-1	Differential pressure test prior to RIH
L-2	Heating and pressurization of tools while RIH
L-3	Absolute pressure test at temperature
L-4	Absolute/differential pressure testing at temperature
L-5	Flowing the well
L-6	Shut in well for pressure buildup
L-7	Start injection for stimulation job, temperature drop due to cold injection fluid
L-8	Screen-out during injection
L-9	Flowing the well while temperature returns to maximum
L-10	Shut in well for pressure buildup
L-11	Final differential pressure test after temperature cycle
L-12	Pulling out of hole, pressure and temperature decreasing

Figure A.1—General Representation of Validation Profile Test Sequence

A.3.6.2 Nonclosure Tools Validation Procedures

A.3.6.2.1 V2 Validation Profile Test Sequence for Nonclosure Tools

The following testing steps shall be performed in the order shown per the acceptance criteria defined in A.3.2. Jars and safety joints are required to also conform to the requirements of A.3.6.2.2.

1) Perform internal and external pressure testing with liquid to a minimum of 105 % of maximum rated differential pressure at ambient temperature or a minimum temperature specified by the supplier/manufacturer at which the tool can withstand 105 % of rated differential pressure. No other external loading is to be applied. (The intent of this step is to expose the tool to its maximum rated pressure before the test vessel is heated to maximum test temperature.)

2) Increase and stabilize the tool at or above its maximum rated temperature and increase the bore and external pressures to a minimum of 105 % of the rated absolute pressure (labels 3, 4, and 11 in Figure A.1) for a minimum of 1 hour. Maintain the tool at its maximum rated temperature through Step 12.

3) Reduce and stabilize both internal and external tool pressures to a value not less than 50 % of the to-be-validated absolute pressure rating.

4) Increase and stabilize the bore pressure to at least 105 % of the maximum absolute pressure rating. While maintaining bore pressure, adjust and stabilize external pressure to achieve 105 % of the differential pressure rating. Hold and record per the acceptance criteria in A.3.2.

5) Increase and stabilize the external pressure to at least 105 % of the maximum absolute pressure rating. While maintaining external pressure, adjust and stabilize bore pressure to achieve 105 % of the differential rating. Hold and record per the acceptance criteria in A.3.2. Step 5 may be performed before Step 4.

6) Adjust and stabilize the bore and external pressures to a value not less than 50 % of the maximum absolute pressure rating.

7) Repeat Steps 4 to 6 one additional time.

8) Increase external pressure by at least 1500 psi and stabilize. (Simulating opening tester valve.)

9) Reduce and stabilize the bore pressure to achieve a minimum of 50 % of the rated differential pressure (annulus high), and hold for a minimum of 24 hours. (Simulating drawdown period.)

10) Reduce and stabilize the external pressure to a value not less than 50 % of the maximum absolute pressure rating. Increase bore pressure and stabilize to achieve a minimum of 20 % of the differential pressure rating (annulus high), and hold the pressures for a minimum of 12 hours. (Simulating buildup period.)

11) Increase external pressure by at least 1500 psi and stabilize. (Simulating opening tester valve as a prelude to stimulation.)

12) Increase and stabilize the bore pressure to achieve a minimum of 20 % of the maximum differential pressure rating (tubing high), and hold for a minimum of 1 hour. (Pressure reversal from stimulation pumping.)

13) Reduce and stabilize the tool to a temperature that is equal to the maximum rated temperature minus the rated temperature drop. The input of heat to extend the cooldown period shall not be allowed. Hold for a minimum of 30 minutes. (Temperature drop due to stimulation pumping.)

14) Increase and stabilize the bore pressure to achieve a differential pressure of a minimum of 50 % of the maximum differential rating (tubing high). Hold for a minimum of 1 hour. (Represents screen-out.)

15) Reduce and stabilize the bore pressure to achieve a differential pressure of a minimum of 50 % of the rated differential pressure (annulus high). Hold for a minimum of 1 hour. (Representing final flow period after stimulation.)

16) Increase the tool's temperature to at or above its maximum temperature rating. Once temperature and pressure have stabilized, hold for a minimum of 12 hours. (Representing temperature rise and final flow period.)

17) Adjust and stabilize the bore pressure and external pressure to a value not less than 50 % of the maximum absolute pressure rating. Hold for a minimum of 30 minutes.

18) Repeat Steps 4 through 6 one time. These steps shall occur after a minimum of 4.5 days in the test facility, exclusive of the initial heat-up period.

19) Cool down the test tool and vessel and remove tool from the fixtures.

20) Drain valves only; after performing the above steps, drain valves shall be pressure integrity tested and functioned in accordance with supplier/manufacturer functional test procedure and acceptance criteria before the drain valve's disassembly and inspection. Prior to this testing, redress activities to the drain valve are not permissible.

21) Perform a drift test as per A.3.2.5.

22) Disassemble and inspect the tested tool(s) according to the supplier/manufacturer's procedures and acceptance criteria.

A.3.6.2.2 V2 Validation Requirements for Jar and Safety Joints

In addition to A.3.6.2.1 or A.3.2.4 as applicable, other functionalities of jars and safety joint designs shall be validated independently, conforming to the documented procedures and acceptance criteria of the supplier/manufacturer. The design validation testing shall replicate the physical conditions to the limits defined in the procedure. Where applicable, the acceptance criteria in A.3.2 shall be utilized.

Jar assemblies and safety joints shall be validated to the profile test sequence as defined in A.3.6.2.1 to assess pressure integrity and seal performance. In addition, for jar assemblies, hydraulic metering/timing characteristics shall be validated at maximum rated temperature. Hydraulic metering/timing characteristics can be validated in a separate test independent of the profile test sequence. Jarring performance and/or impact testing is currently beyond the scope of this standard.

A.3.6.2.3 V1 Validation Profile Test Sequence for Nonclosure Tools

V1 validation level shall include successful completion of the V2 test profile A.3.6.2.1 and a supplemental gas test to validate the integrity of the tool with gas pressure applied from the bore. The inability to complete any portion of the V1 testing within the defined limits shall be considered a test failure. A successful completion of a complete V1 test is required to achieve a V1 rating.

Testing shall consist of the following.

1) Install tool in the test facility and increase test vessel temperature up to the maximum rated temperature of the tool.

2) At rated temperature, increase internal pressure to maximum differential pressure rating. After stabilization, confirm pressure integrity per the gas testing acceptance criteria in A.3.2.2.3.

3) Terminate test. Cool down test vessel and remove tool from test setup.

4) Disassemble and inspect per supplier/manufacturer's documented procedures and prepare a test report as defined in A.3.6.5.

A.3.6.3 Single-cycle Tool Validation Procedures

A.3.6.3.1 General

Differential pressure tests shall be performed at a minimum of 105 % of the supplier/manufacturer rated maximum differential pressure of the closure mechanism from above and below (as applicable), for tools that function as closure devices. Single-cycle tools shall be operated in accordance with the supplier/manufacturer's procedures at the indicated times per the profile test sequence of A.3.6.3.2.

A.3.6.3.2 V2 Validation Profile Test Sequence for Single-cycle Tools

The following testing steps shall be performed in the order shown per the acceptance criteria defined in A.3.2.

1) For tools having a closure mechanism in an initially closed position, apply 105 % of the rated pressure against the closure mechanism in the appropriate direction(s) at ambient temperature or a minimum temperature specified by the supplier manufacturer at which the closure mechanism can withstand 105 % of maximum rated differential pressure. (The intent of this step is to expose the closure mechanism to its maximum rated pressure before the test vessel is heated to maximum test temperature.)

2) Perform both an internal and external pressure test with liquid to a minimum of 105 % of maximum rated differential pressure at ambient temperature or a minimum temperature specified by the supplier/manufacturer at which the tool can withstand 105 % of maximum rated differential pressure. No other external loading is to be applied. (The intent of this step is to expose the tool to its maximum rated pressure before the test vessel is heated to maximum test temperature.)

3) Increase and stabilize the tool at or above its maximum rated temperature and increase the bore and external pressures to a minimum of the tool's maximum rated absolute pressure for a minimum of 1 hour. Maintain the tool at its maximum rated temperature through Step 15.

4) Reduce and stabilize bore and external pressures to a value not less than 50 % of the maximum absolute pressure rating.

5) Increase and stabilize the bore pressure to at least 105 % of the maximum absolute pressure rating (labels 3, 4, and 11 in Figure A.1). While maintaining bore pressure, adjust and stabilize external pressure to achieve 105 % of the differential pressure rating. Hold and record per the acceptance criteria in A.3.2.

6) Increase and stabilize the external pressure to at least 105 % of the maximum absolute pressure rating (if applicable). While maintaining external pressure, adjust and stabilize bore pressure to achieve 105 % of the differential rating. Hold and record per the acceptance criteria in A.3.2. Step 6 may be performed before Step 5.

7) Adjust and stabilize the bore and external pressures to a value not less than 50 % of the maximum absolute rating.

8) Repeat Steps 5 to 7.

9) Pressure test the work string tester valve to a minimum of 105 % of the rated differential pressure of the closure mechanism from above. Equalize the pressure across the closure device. Repeat this pressure cycle a minimum of 10 times or the supplier/manufacturer's rated number of pressure cycles if greater than 10. Pressure leakage criteria per A.3.2 shall be checked after $^{1}/_{2}$ of the number of pressure cycles and after the final pressure cycle. If the tool being tested is not a tubing string tester valve, proceed to Step 11.

10) Activate work string tester valve to disable further operation.

11) Increase external pressure by at least 1500 psi and stabilize. (Simulating opening tester valve.)

12) Reduce and stabilize the bore pressure to achieve 50 % of the rated differential pressure (annulus high), and hold for a minimum of 24 hours. (Simulating drawdown.)

13) Reduce and stabilize the external pressure to a value not less than 50 % of the maximum absolute rating. Increase bore pressure and stabilize to achieve a minimum of 20 % of maximum differential pressure rating (annulus high). Hold the pressures for a minimum of 12 hours. (Simulating buildup period.)

14) Increase external pressure by at least 1500 psi and stabilize. (Simulating opening tester valve as a prelude to stimulation.)

15) Increase and stabilize the bore pressure to achieve a minimum of 20 % of the maximum differential pressure rating (tubing high), and hold for a minimum of 1 hour. (Pressure reversal from stimulation pumping.)

16) Reduce and stabilize the tool to a temperature that is equal to the maximum rated temperature minus the rated temperature drop. The input of heat to extend the cooldown period shall not be allowed. Hold for a minimum of 30 minutes. (Temperature drop due to stimulation pumping.)

17) Increase and stabilize the bore pressure to achieve a differential pressure of a minimum of 50 % of the maximum differential rating (tubing high). Hold for a minimum of 1 hour. (Represents screen-out.)

18) Reduce and stabilize the bore pressure to achieve a differential pressure of a minimum of 50 % of the rated differential pressure (annulus high). Hold and record for a minimum of 1 hour. (Representing final flow period after stimulation.)

19) Increase the tool's temperature to at or above its maximum temperature rating. Once temperature and pressure have stabilized, hold for a minimum of 12 hours. (Representing temperature rise and final flow period.)

20) Adjust and stabilize the bore pressure and external pressure to a value not less than 50 % of the maximum absolute rating. Hold for a minimum of 30 minutes.

21) Repeat Steps 5 through 7 one time. These steps shall occur after a minimum of 4.5 days in the test facility, exclusive of the initial heat-up period.

22) Activate single-cycle tool with 105 % of the rated differential pressure across the valve (except for the tubing tester valves that were cycled at Step 10). For tools with tubing closure devices, perform a minimum of 105 % of the maximum differential pressure across closure device(s) with acceptance criteria as defined in A.3.2 for each applicable pressure differential direction.

23) Cool down the test tool and vessel and remove tool from the fixtures.

24) Perform a drift test as per A.3.2.5.

25) Disassemble and inspect the tested tool(s) according to the supplier/manufacturer's procedures and acceptance criteria.

A.3.6.3.3 V1 Validation Profile Test Sequence for Single-cycle Tools

V1 validation level shall include successful completion of the V2 test profile A.3.6.3.2 and a supplemental gas test to validate the integrity of the tool with gas pressure applied from the bore or across the closure device where applicable. The inability to complete any portion of the V1 testing within the defined limits shall be considered a test failure. A successful completion of a complete V1 test is required to achieve a V1 rating.

Testing shall consist of the following.

1) Install tool in the test facility and increase test vessel temperature up to the maximum rated temperature of the tool.

2) At rated temperature, increase bore pressure to 105 % of the rated differential pressure (tubing high). Confirm pressure integrity per the gas testing acceptance criteria A.3.2.2.3.

3) For a safety valve, activate the tool and apply 105 % of the rated differential pressure across the closure mechanism in the direction for which the device is rated. Confirm pressure integrity per the gas testing acceptance criteria A.3.2.2.3.

4) Terminate test. Cool down the test vessel and remove tool from test setup.

5) Disassemble and inspect per supplier/manufacturer's documented procedures and prepare a test report as defined in A.3.6.5.

A.3.6.4 Multi-cycle Tool Validation Procedures

A.3.6.4.1 General

Multi-cycle tools must be activated at the appropriate time as shown in the test procedure such that the validation profile is satisfied. In the case where the tool functions as a closure device, perform pressure test(s) from above and below as applicable at 105 % of the differential rating of the closure device. In order to accommodate the total number of valve cycles during the test, it is permissible to perform additional valve cycles outside of the required hold periods; the represented drawdown and buildup periods are to be maintained as prescribed in A.3.6.4.2.

Multi-cycle tools shall be functioned at the prescribed points in the testing sequence in A.3.6.4.2. Two or more valve cycles are performed at each of these points with pressure integrity testing performed after the last cycle at each of the designated points in the testing profile. The performance of more than two cycles at each point in the testing profile are at the discretion of the supplier/manufacturer; however, acceptance criteria shall be met. The supplier/manufacturer may perform valve cycles in addition to those required. Additional cycles may be performed at the end of the test to establish the total number of validated cycles. These additional cycles shall conform to the leak acceptance criteria to be included in the total number of validated valve cycles.

For multi-cycle tools having an insufficient number of rated valve cycles necessary to complete all prescribed open and close operations in A.3.6.4.2, one valve cycle may be eliminated from Steps 9, 19, and 23, as required, to complete the testing sequence A.3.6.4.2. If the prescribed sequence A.3.6.4.2 is not able to be achieved after the foregoing reduction in valve cycles because of an insufficient number of rated cycles, then Steps 9 and 19 of A.3.6.4.2 may be eliminated (in order), as required, to complete the testing sequence A.3.6.4.2. If the tool's rated number of valve cycles remains insufficient to complete sequence A.3.6.4.2, the tool may be alternatively tested following sequence A.3.6.3.2 (single-cycle tools), but with all open-close cycles executed at Step 22 of A.3.6.3.2. In this case, one open-close cycle shall be used to test the valve(s) rated opening differential pressure in both directions. A final pressure integrity test shall be conducted in applicable direction(s) after the final cycle.

A.3.6.4.2 V2 Validation Profile Test Sequence for Multi-cycle Tools

The following testing steps shall be performed in the order shown per the acceptance criteria defined in A.3.2.

1) If the closure mechanism(s) is initially open, function it closed (if applicable) and apply a minimum of 105 % of the rated differential pressure of the closure device at ambient temperature or at a temperature specified by the supplier/manufacturer against the closure mechanism(s) in the appropriate direction(s) and confirm pressure integrity per A.3.2.2.

2) Perform internal and external pressure testing with liquid to a minimum of 105 % of maximum rated differential pressure at ambient temperature or a minimum temperature specified by the supplier/manufacturer at which the tool can withstand 105 % of maximum rated differential pressure. No other external loading is to be applied. (The intent of this step is to expose the tool to its maximum rated pressure before the test vessel is heated to maximum test temperature.)

3) Increase and stabilize the tool at or above its maximum rated temperature and increase the bore and external pressures to a minimum of 105 % of the tool's maximum rated absolute pressure for a minimum of 1 hour. Maintain the tool at its maximum rated temperature through Step 15.

4) Reduce and stabilize bore and external pressures to a value not less than 50 % of the maximum absolute pressure rating.

5) Increase and stabilize the bore pressure to at least 105 % of the maximum absolute pressure rating (labels 3, 4, and 11 in Figure A.1). While maintaining bore pressure, adjust and stabilize external pressure to achieve 105 % of the differential pressure rating. Hold and record per the acceptance criteria in A.3.2.

6) Increase and stabilize the external pressure to at least 105 % of the maximum absolute pressure rating. While maintaining external pressure, adjust and stabilize bore pressure to achieve 105 % of the differential rating. Hold and record per the acceptance criteria in A.3.2. Step 6 may be performed prior to Step 5.

7) Adjust and stabilize the bore and external pressures to a value not less than 50 % of the maximum absolute rating.

8) Repeat Steps 5 to 7 one time.

9) Perform a minimum of two valve cycles. Verify pressure integrity of the closure mechanism(s) per A.3.2 after the last cycle.

10) Increase external pressure by at least 1500 psi and stabilize (simulating opening tester valve) and open the tester valve (if applicable).

11) Reduce and stabilize the bore pressure to achieve a minimum of 50 % of the rated differential pressure (annulus high), and hold for a minimum of 24 hours. (Simulating drawdown period.)

12) Close the tester valve (if applicable). Reduce and stabilize the external pressure to a value not less than 50 % of the maximum absolute rating. Increase bore pressure and stabilize to achieve a minimum of 20 % of the differential pressure rating (annulus high), and hold the pressures for a minimum of 2 hours. (Simulating buildup period.)

13) Steps 13a to 13d (closure mechanism tests against rated opening differential pressure) may be performed in an alternative order when technically appropriate. The pressure integrity test shall be performed after each valve closure in the direction of applied differential.

    a) Open the tester valve against the rated opening differential pressure from below followed by closure and pressure integrity testing per A.3.2.

    b) Open the tester valve against the rated opening differential pressure from above followed by closure and pressure integrity testing per A.3.2.

    c) Open the circulating valve against the rated internal to external opening differential pressure followed by closure and pressure integrity testing per A.3.2.

    d) Open the circulating valve against the rated external to internal opening differential pressure followed by closure and pressure integrity testing per A.3.2.

    e) Return the test conditions to those defined in Step 12 after a minimum total time of 10 hours, which includes the time required to perform Steps 13a to 13d. During this time, or with additional time as selected by the supplier/manufacturer, additional valve cycles may be performed.

14) Increase external pressure by at least 1500 psi and stabilize. (Open tester valve as a prelude to stimulation.) If the tool operates by the application of external pressure, apply the pressure required to function the tool.

15) Increase and stabilize the bore pressure to a minimum of 20 % of the differential pressure rating (tubing high), and hold for a minimum of 1 hour. (Pressure reversal from stimulation pumping.)

16) Reduce and stabilize the tool to a temperature that is equal to the maximum rated temperature minus the rated temperature drop. Hold for a minimum of 30 minutes. (Temperature drop due to stimulation pumping.)

17) Increase and stabilize the bore pressure to achieve a differential pressure of a minimum of 50 % of the maximum differential rating (tubing high). Hold for a minimum of 1 hour. (Represents screen-out.)

18) Reduce and stabilize the bore pressure to achieve a differential pressure of a minimum of 50 % of the rated differential pressure (annulus high). Hold and record for a minimum of 1 hour. (Representing initial pressure reversal caused by final flow period after stimulation.)

19) Perform a minimum of two valve cycles per closure mechanism. Verify pressure integrity of the closure mechanism(s) per A.3.2 after the last cycle.

20) Increase the tool's temperature to at or above its maximum temperature rating, and adjust the bore pressure to a minimum of 50 % of the rated differential pressure (annulus high). The pressure is allowed to fluctuate during the temperature increase. Once temperature and pressure have stabilized, hold for a minimum of 12 hours. (Representing temperature rise during final flow period.) During the last 2 hours, additional valve cycles may be performed if prescribed by the supplier/manufacturer.

21) Adjust and stabilize the bore pressure and external pressure to a value not less than 50 % of the maximum hydrostatic rating. Hold for a minimum of 30 minutes.

22) Repeat Steps 5 through 7 one time. These steps shall occur after a minimum of 4.5 days in the test facility, exclusive of the initial heat-up period.

23) Perform a minimum of two valve cycles per closure mechanism. Verify pressure integrity of the closure mechanism(s) per A.3.2 after the last cycle.

Additional cycles may be performed at the supplier/manufacturer's discretion to establish the total number of validated cycles. Verify pressure integrity of the closure mechanism(s) per A.3.2 after the last cycle.

1) Cool down the test tool and vessel and remove tool from the fixtures.

2) Perform a drift test as per A.3.2.5.

3) Disassemble and inspect the tested tool(s) according to the supplier/manufacturer's procedures and acceptance criteria.

A.3.6.4.3 V1 Validation Profile Test Sequence for Multi-cycle Tools

V1 validation level shall include successful completion of the V2 test profile A.3.6.4.2 and a supplemental gas test to validate the integrity of the tool with internal gas pressure applied and across the closure device. For the case of a tester valve, the pressure test need only be applied from below the ball. The test of both the tester valve and circulating valve shall be conducted both before and after the valves have been shifted. The valves may be shifted by a documented procedure, and it is not necessary to have pressure applied to the valve when it is shifted. The inability to complete any portion of the V1 testing within the defined limits shall be considered a test failure. A successful completion of a complete V1 test is required to achieve a V1 rating.

Testing shall consist of the following.

1) For a tester valve and/or circulating valve, place the closure mechanisms in the closed position and install tool in the test facility.

2) Increase test vessel temperature up to the maximum rated temperature of the tool.

3) At rated temperature, increase internal pressure of the tool to establish maximum differential pressure rating. For a tester valve, equalize pressures on both sides of the closure mechanism. Confirm pressure integrity per the gas testing acceptance criteria A.3.2.2.3.

4) For a tester valve, bleed pressure from above the closure mechanism and establish the rated differential pressure from below. Confirm pressure integrity per the gas testing acceptance criteria A.3.2.2.3.

5) Terminate test. Cool down test vessel and remove tool from test setup.

6) Remove tool from test vessel. Perform drift test. Disassemble and inspect.

A.3.6.5 Test Reporting

A final report of the design validations shall be prepared by a qualified person and approved by a qualified person other than the person who prepared the report. The test report becomes a portion of the tool design documentation. The report shall as a minimum include:

a) testing location(s), date, and person performing the testing;

b) the tool's unique identification, such as part number and serial number;

c) procedures used and records required by those procedures;

d) detailed results and discussion of results including whether or not the test was successful;

e) approval indications such as signatures.

A.3.6.6 Validation of Alternative Seal Compounds

A.3.6.6.1 Validation of Alternative O-ring Compounds or Change of Supplier

This section allows validation of alternate seal compounds or a change of supplier by fixture testing of the largest and smallest sealing diameters of the same cross section (typically referred to as series). This section applies only to O-ring sealing systems, having the same gland width, depth, extrusion gap, backup system configuration, static/dynamic conditions, and justifiably equivalent metal displacement due to applied pressure/loading.

In lieu of a fixture test, alternate seal compounds that have been validated in an assembled tool may be considered to be validated for other tools when the requirements of this section have been met.

For V1, V2, and V3 validated tools, alternative seal compounds can be utilized when all requirements of this section are met. A change in supplier of the same compound or a change in compound composition can be substituted and validated by utilizing a test fixture instead of performing a complete tool validation test.

Alternative validation of seal compounds shall be performed within the following limits.

a) The seal compound is to be rated for a temperature and/or pressure that is not outside of the previously validated tool assembly. If outside the validated tool's ratings, a tool validation test is required.

b) The test fixture shall be at or beyond minimum material condition seal gland dimensions (squeeze and extrusion gap) for a given cross-section (series) per ISO 3601-1 and shall have the same or roughest surface finish specified in the validated design(s).

c) Dynamic sealing systems shall be tested under dynamic conditions.

d) A test, composed of two different O-ring sizes for a given cross-section (series) per ISO 3601-1 representing the smallest and largest diameters in the validated assembly, that is performed to validate the same series of O-rings/seal configurations used in the validated assembly and shall be exposed to the same pressure, temperature, operational cycles, and time duration as A.3.6.3.2 and A.3.6.3.3.

e) Acceptance criteria per A.3.6.3.2 and A.3.6.3.3, as applicable.

The seal validation procedure and acceptance criteria shall be prepared by a qualified person and approved by a second qualified person. The procedures and validation results shall be included in the tool's design records. Reporting requirements shall comply with A.3.6.5 with the exception that the tool part number shall be replaced by the compound identifier.

A.3.6.6.2 Validation of Alternative Compounds for Sealing Systems Other Than O-rings

For sealing systems other than O-rings, the supplier/manufacturer shall have documented procedures for testing and validating alternate seal compounds or a change of suppliers. The test procedure shall adequately replicate the seal application. The procedures, acceptance criteria, and testing results shall be approved by a qualified person.

A.3.6.6.3 Alternate Validation of Upper Temperature Rating and Associated Temperature Drop

For tools that have successfully completed validation testing, seal compounds can be validated to a new upper temperature and corresponding temperature drop by fixture testing performed to the requirements of A.3.6.6.1 and A.3.6.6.2. The new upper temperature and corresponding temperature drop must not be outside of the previously validated tool assembly validated ratings.

Validation of the new temperature ratings may be established for either a previously validated compound or after a change in compound composition or supplier, provided that all requirements of this section are met.

The paired upper temperature and corresponding temperature drop provide validated values for a tool's performance. The tool is validated to operate in well conditions as high as the upper temperature rating and with an associated temperature drop that typically occurs during fluid injection/stimulation operations.

A.3.6.6.4 Establishment of Minimum Temperature at Which Tool Can Withstand 105 % of Rated Differential Pressure Rating

This section provides a method of establishing a new minimum temperature at which a tool can withstand 105 % of its rated differential pressure rating after a previous validation of a full tool assembly. Such a validation is required after a change in supplier of the same seal compound or a change in compound composition.

a) The validation shall be established by performing an internal pressure test on a fully assembled tool.

b) Heat or cool the tool to the intended test temperature.

c) Perform an internal pressure test to 105 % of the tool's rated differential pressure.

After stabilizing, verify pressure integrity of the tool per A.3.2.2.2.

Annex B
(normative)

Factory Acceptance Testing

B.1 General Requirements

To conform to the requirements of this annex, each production tool manufactured shall pass all requirements within the limits specified, per the acceptance criteria defined, and the results required for functional validation. All tests and tool-related data for a valid, successful test shall be recorded in detail and retained after approval by a qualified person.

FAT shall conform to the provisions of Section 7 as applicable.

Verify that the model and serial numbers appearing on the tested tool are in agreement with and included on the test report. The testing shall be conducted on a complete assembly. All required tests shall be passed in all aspects within the defined acceptance criteria and in the order presented (as applicable) without rebuild or redress of the test assembly during the processing.

For completion of a successful test, the tool shall be tested and perform within the limits specified for all required steps. Each evaluation report shall be signed and dated by the qualified person(s) conducting and approving the test results.

B.2 Testing Requirements

B.2.1 General

A factory acceptance test shall be performed to a documented factory acceptance test procedure, which shall comply with the requirements of this section. The factory acceptance test procedures shall include acceptance criteria for each assembly, as applicable, to the tool design.

Fluids used for pressure testing shall be water, with or without additives, or hydraulic oil/heat transfer fluid. The test fluid shall be visibly free from particulate matter and/or other material that have the potential of plugging small leaks. All fluids used in the testing shall be defined and documented in the test report.

B.2.2 Body Pressure Integrity Test(s)

Each tool shall be pressure tested with liquid at the room temperature rated internal pressure using supplier/manufacturer procedures by a qualified person(s). Any visible leakage from the tool is cause for test failure. The pressure test acceptance criteria is no more than 1 % reduction in the maximum rated differential pressure, with a decreasing rate of change, over a period of 15 minutes after sufficient time has been allowed for stabilization. The time period for stabilization is at the discretion of the supplier/manufacturer.

Each tool that includes pressure-retaining chamber(s) not tested in the body or integrity functional tests shall have the pressure-retaining chamber(s) hydrostatically pressure tested (as applicable) at no less than its maximum rated internal pressure at room temperature, using supplier/manufacturer procedures by a qualified person(s). Included are hydraulic or gas chambers used in the operation of the tool and/or other similar pressure-retaining chambers. Any measured and/or visible leakage from the tool is cause for test failure. The pressure test acceptance criteria is no more than 1 % reduction in the maximum rated differential pressure, with a decreasing rate of change, over a period of 15 minutes after sufficient time has been allowed for stabilization at the end of a pressure hold. The time period for stabilization is at the discretion of the supplier/manufacturer.

B.2.3 Closure Mechanism Integrity Test

A pressure test shall be performed across the closure mechanism in its direction(s) of sealing, where a closure mechanism is present. For closure mechanisms communicating to the annulus, external pressure testing is not required. Testing shall be performed at the test pressure associated with ambient temperature as described in the factory acceptance test procedure.

For test pressures greater than 500 psi, follow the acceptance criteria in B.2.2. For test pressures of 500 psi or less, the acceptance criteria shall be no more than 5 % reduction in the tested differential pressure, with a decreasing rate of change, over a period of 15 minutes after sufficient time has been allowed for stabilization at the end of a pressure hold.

B.2.4 Operational Test

Each tool shall be tested to open/close or functioned through its operational cycle(s) at ambient temperature where applicable, in accordance with the supplier/manufacturer's defined procedures as described in the factory acceptance test procedure. The test results shall conform to documented acceptance criteria and limits.

B.2.5 Special Features Test

Special features shall be tested in accordance with the supplier/manufacturer's documented test procedures, including acceptance criteria. These tests may be incorporated into the existing sequence of factory acceptance tests, providing they do not cause operational limitations to the tool. Results shall conform to the documented acceptance criteria.

B.2.6 Drift Test

After all functional testing steps are complete, perform a drift test per A.3.2.5. The drift bar unique identifier shall be recorded in the FAT report.

Annex C
(normative)

Service Center Requirements

C.1 General

This annex provides the requirements for post-manufacturing activities of downhole test tools and related equipment such as maintenance, repair, and servicing at service centers. Included are the requirements for downhole test tool service centers, including capabilities, records retention, tool identifications, receiving inspections, traceability, functional testing, pre-job evaluations, post-use evaluations, periodic tool inspections, tool repairs, and quality requirements. All testing and inspection procedures and results shall be documented and retained as specified in 7.2.

The requirements for the original manufacture of these tools are covered in Section 7.

C.2 Service Center Requirements

A service center is a physical location apart from the well site. Personnel performing inspection, testing, redress, and repair operations described in this annex shall be trained and qualified in compliance with the supplier/manufacturer procedures. Additionally, personnel approving the interpretation of nondestructive testing (NDE) shall be qualified per ASNT SNT-TC-1A Level II or equivalent.

Each service center shall provide the qualified staff and calibrated tools and systems necessary to perform the defined evaluations within the acceptance criteria defined in the procedures. All tools and equipment used for measurement of acceptance criteria shall be calibrated per 7.5.1. The traceability and tracking of each assembly and component shall be controlled throughout the processing and shall conform to a documented procedure. Qualified personnel shall have immediate access to all necessary records, such as diagrams and technical data and instructions necessary to complete the designated work according to the requirements of the procedures.

The service center shall provide replacement components that conform to the documented design and manufacturer requirements, including testing and retained documentation.

The service center shall have documented procedures for storage of tools and components to prevent deterioration/damage. Tools and components shall be appropriately packaged for transport to prevent deterioration/damage during shipping. All material provided as protection for transport, with the exception of thread protectors, shall be clearly identified for removal prior to use of the tool.

C.3 Documentation

C.3.1 General

Each service center shall be supplied with the documentation by the supplier/manufacturer according to 7.2.2.4. The following documentation shall be available for review by a user/purchaser upon request.

C.3.2 Serial Number Specific Documentation

The following requirements shall apply to this section:

— Shear/burst device testing records (where applicable).

— Maintenance records.

— Approved modification records.

— Service completion certificate.

C.3.3 Generic Documentation

The following requirements shall apply to this section:

— Datasheet/technical specifications.

— Performance envelope.

— Summary validation records.

— Job history (by tool model).

C.3.4 Records Retention

Records of each tool's status, use, repair, redress testing, and evaluations shall be retained in a records retention system that is accessible by the service center, conforming to the requirements of 7.2.1. The service center shall be able to provide, as a minimum, access to the most recent repair, redress testing, and evaluation records to operational personnel. For tools containing electronics that record temperature-time statistics, such data shall be retained for each electronic assembly and accessible to rig-site personnel.

Job history records shall be available in addition to the traceability records. These records are to be retained for at least 3 years after a tool has been removed from service.

C.4 Anticipated Tool Usable Life Limits Defined

The anticipated life of a tool assembly is set by the supplier/manufacturer, and it may vary according to tool design. Generally, mechanical tools are evaluated by the condition and inspection of their components and have an unspecified lifetime when all components meet the supplier/manufacturer's specifications.

Generally, electrical/electronic components or subassemblies will have a prescribed lifetime based upon hours and temperature, with replacement performed once its qualified lifetime has been achieved. Replacement of these electrical/electronic components or subassemblies may cause the tool to be retested to ensure its full operation as prescribed by the supplier/manufacturer.

When the tool assembly is serviced, the tool records will be updated and unique identification numbers for each replaced component shall be logged for traceability. Each tool shall be tracked and associated with the original unique serial number until the time the tool serial number is retired and the tool is scrapped, which is also duly recorded.

C.5 Receiving Inspections for Newly Received Tools

When tools are received at a service center, either new or transferred, they shall be disassembled/evaluated according to documented Level 2 redress procedures (see C.6.3) by qualified personnel and the component parts evaluated as required by the supplier/manufacturer. Each tool's identification and the component's unique identification shall be recorded on an inspection report. This report shall be archived and included in each tool's use history.

C.6 Tool Inspection/Test Levels

C.6.1 General

Inspections and testing shall be performed to ensure the tool performance remains as originally designed and the safety is not compromised. Inspections are categorized in the following three levels.

— Level 1—Pre-run inspection/test.

— Level 2—Post-job inspection, service, and function test (commonly known as redress).

— Level 3—Periodic (and post severe service) inspection, service, and function test.

Inspection, service, and functional testing shall be performed per the manufacturer's maintenance instructions, with the minimum compliance as per the following.

C.6.2 Level 1 Inspection/Test (Pre-run and Well Site)

If tools have been stored at the service center for a defined length of time after a Level 2 redress (see C.6.3), a Level 1 inspection/test shall be performed prior to mobilization to confirm functionality.

Level 1 inspection/test procedure and associated acceptance criteria shall be provided by the supplier/manufacturer and be included in the tool's operating/maintenance manual(s). At a minimum, tests shall include drift, visual inspection, pressure integrity, and function tests.

Some tool designs may require customized settings for specific applications such as selection of rupture discs and appropriate nitrogen charging values. These steps shall be performed according to documented procedures and in comparison with the applications requirements and the tool's capabilities by qualified personnel. Setup parameters and methods shall be defined in the user/supplier's documentation.

Local customer requirements, regulatory requirements and supplier/manufacturer management requirements shall also be implemented in the documented pre-use evaluations.

A Level 1 inspection/test is also routinely performed at the well site prior to a run to confirm that the tool is functioning properly after transport.

C.6.3 Level 2 Service (Redress)

A Level 2 service (redress) is performed after a tool is received by the service center to ensure that the safety, integrity, and capability of the tool remain as per the supplier/manufacture's design. The tool may have been received by the service center as a newly manufactured tool, as a used asset from another service center, or after performing a job in the field. The service center should have a process in place for receiving tools from a well site, including washing/flushing to remove corrosive fluids and checking for potential hazardous conditions such as trapped pressure, H_2S, and naturally occurring radioactive material (NORM). Appropriate health, safety, and environment (HSE) precautions should be taken at the service center.

The Level 2 service procedure shall be provided by the supplier/manufacturer for each tool design. The procedure shall be included in the tool's operating/maintenance manual(s). Replacement components shall conform to the requirements applied to the original component parts.

Prior to performing a Level 2 service, a tool's maintenance records shall be reviewed to determine if periodic Level 3 maintenance is required (see C.6.4).

The following topics shall be addressed in the Level 2 service process per supplier/manufacturer requirements:

a) disassembly and cleaning;

b) visual inspection of parts, including all sealing surfaces;

c) replacement of elastomeric sealing elements;

d) inspection and/or replacement of sealing components;

e) battery replacement (if applicable);

f) logging and reporting of replaced components in the equipment data files;

g) reassembly;

h) drifting;

i) for nitrogen charged tools, nonhydrocarbon based greases and oils having a sufficiently high flash point shall be used on the chamber areas, and nitrogen purity shall not exceed 1 % oxygen;

j) functional testing;

k) after completion of functional testing, install thread protectors and seal all open connections to prevent damage.

Additional application-specific testing is permissible when agreed to by the user/purchaser and supplier/manufacturer. Following reassembly, each tool shall be internally pressure and function tested per C.6.2. Tools acceptable for use shall have successfully completed the required testing acceptance criteria and shall be marked/tagged as such.

For tools that have been placed in storage for a defined period of time, refer to C.6.2.

C.6.4 Level 3 Service (Periodic Evaluation)

This service ensures that the safety, integrity, and capability of the tool remain as per the design requirements. Level 3 service shall be performed in the event of any of the following:

a) every 20 jobs or 3 years, whichever comes first;

b) before any job with expected temperatures above 85 % of its temperature rating or pressures exceeding 85 % of the tool's pressure ratings;

c) following any job in which the above conditions were exceeded;

d) following any job with H_2S concentrations exceeding 0.05 psia partial pressure for tools that are not compliant with NACE MR0175/ISO 15156;

e) following any job in which the tensile load exceeded 85 % of the tool's tensile rating or after jarring;

f) following use in any harsh environments as determined by supplier/manufacturer's qualified personnel, such as high concentrations of CO_2, H_2S, acids, and solids.

Level 3 service shall include all Level 1 and Level 2 service and shall include the following as prescribed by the supplier/manufacturer:

a) NDE testing of axial load-bearing threads,

b) testing and verification of mechanical springs,

c) function and pressure integrity test in accordance with Annex B.

Level 3 service may include the following as prescribed by the supplier/manufacturer:

a) NDE on load-bearing and pressure-retaining components;

b) wall thickness measurement of all internal diameter components—components with wall thickness below the manufacturer's acceptable corrosion/erosion allowance require replacement;

c) gauging of threaded load-bearing connections;

d) radiography on welds.

All criteria shall conform to the supplier/manufacturer's documented acceptance requirements, before the tool is returned to service.

C.7 Repair

Repair of tools and related equipment shall be conducted according to procedures established by the supplier/manufacturer and shall return the tool to a condition meeting all requirements stated in this specification.

C.8 Quality Requirements

C.8.1 General

The service center shall have a quality management system implemented that ensures that the requirements defined within this annex are conformed to. As a minimum, the following are required for the service center quality records.

— Utilize current maintenance and operating manuals and datasheets.

— Calibration of test equipment and tools shall conform to 7.5.1.

— Training and competency certification of personnel is maintained and auditable.

— Pressure test facilities comply to all applicable regulations [i.e. Occupational Safety and Health Administration (OSHA), Pressure Equipment Directive (PED), Norsk Sokkels Konkuranseposisjon (NORSOK)].

— Equipment databook/equipment dossier is maintained and updated when a traceable component is replaced.

— Inspection and maintenance checklists/reports and test reports shall be signed by a qualified person other than the person performing the functions.

— Inspection and maintenance checklists/reports and test reports shall be archived in accordance with the document retention policy in 7.2.

— Replacement components shall conform to the requirements applied to the original component parts.

C.8.2 Unique Identification of Tools and Components

All load-bearing/pressure-retaining components and any other components designated by the manufacturer/supplier shall maintain traceability from beginning to end of the tool/component's life cycle. A record system shall be maintained that contains the lifetime service records for each serialized tool assembly.

The location, use, and environmental exposure shall be recorded by tool serial number. Parts within a tool shall be traceable to the tool serial number in which they are installed. Traceable parts without serialization or batch marking on the part shall have traceability information recorded in the service center documentation for that tool at the time of reassembly.

Common hardware and other nontraceable parts are exempted from this requirement.

C.8.3 Design Revision Updates and Limitations

The service center shall implement mandatory design revisions as provided by the supplier/manufacturer. Service center modifications are not allowed unless expressly authorized and approved by the supplier/manufacturer. Service center modifications shall be documented in accordance with C.3.

Annex D
(normative)

Performance Rating Envelopes

D.1 General

Downhole test tools shall be supplied with a performance rating envelope. The supplier/manufacturer shall state the differential pressure, temperature, and axial performance ratings, as applicable for the tool design, and illustrate those capabilities in static performance envelopes. These envelopes are graphic illustrations of the downhole test tool performance limits derived from the combined effects of differential pressure and axial loads. An example envelope is illustrated in Figure D.1.

The performance envelope shall define the supplier/manufacturer's specified ratings of the tool design corresponding to a specific tool state, for example, the closure mechanism open, or ends closed. The performance envelopes can be presented as a series of curves differentiated by color or line type, or the envelopes may be presented as separate curves. The curves shall be clearly identified with an appropriate legend. The boundary of the envelope defines the design's maximum performance as rated by the supplier/manufacturer.

D.2 Performance Envelope Required Data

For V1/V1-TP and V2/V2-TP tools, the envelopes are based upon testing results in conformance with Annex A and may include calculated data. For V3/V3-TP tools, the envelopes are based upon justification as described in A.3.5 and E.4 and calculated data and may include existing test data on full tool assemblies. The envelope documentation shall as a minimum include the following criteria.

a) The boundary lines of the envelope represent the manufacturer's rated performance. Temperature limitations shall be clearly indicated on the envelope.

b) The ratings of the tool shall include the tool end connections. Any dependency of the rating on the tool end connection design shall be indicated on the envelope.

c) Bending- and buckling-induced curvature is not accounted for in the envelope.

d) Any absolute pressure limitations of the tool shall be identified with the operating envelope.

e) The axial load shall be on the X axis.

f) Pressure shall be on the Y axis.

g) Axes shall be clearly labeled with numerical values, and the associated engineering units shall be indicated.

h) More than one curve may be displayed on the envelope if a legend is included for explanation.

i) The tool(s) covered by the envelope shall be specified on the envelope.

j) The envelope shall be prepared and approved by a qualified person(s).

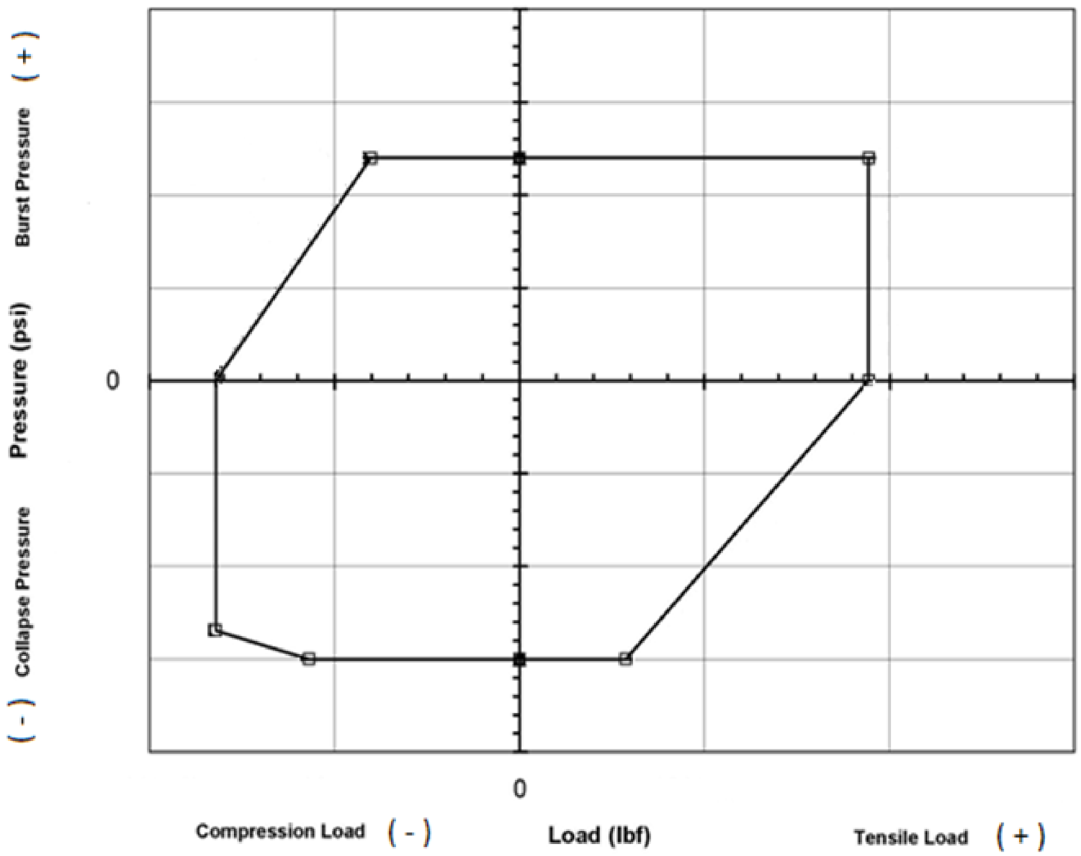


Figure D.1—Example Performance Envelope

Annex E
(normative)

Well Testing Packer Requirements

E.1 General

Each well test packer design provided in accordance with this specification shall conform to the requirements of this annex. Each well testing packer shall pass all requirements within the limits specified and per the acceptance criteria defined, with suitable documentation of the applicable processes, acceptance criteria, testing, and evaluation results. The defined evaluations and testing results shall validate the stated performance and capabilities of the packer following approval of the testing results by a qualified person(s).

The required procedures for each design validation test shall be documented by the supplier/manufacturer and conform to the requirements of Sections 5, 6, and 7. All tests and packer related data for a valid, successful test shall be recorded and retained as a portion of the packer's design records following approval by a qualified person(s).

Validation test facilities shall conform to the requirements of A.1.2. Test facility anomalies occurring during testing that have no effect on packer testing performance may be accepted when documented and approved by a qualified person(s).

External packer accessories that are separable, such as hold-down devices, fluid bypass systems, indexing mechanisms, etc., can be validated separately in accordance with Annex A as related equipment, as determined and documented by a qualified person. Alternatively, the external packer accessories can be tested as part of the well testing packer assembly in accordance with Annex E.

The design validation grade shall be selected from Table E.1 for each design to be provided. These validation grades are proof of design evaluations that are performed on the base design. Packers qualified to higher grades of design validation may be considered qualified for the lower grades of design validation. Table E.1 presents a summary of the testing to be performed for each validation grade.

E.2 Packer Rating Requirements

Packer ratings shall be established using the supplier/manufacturer's documented procedures, based on material properties at rated temperatures, and approved by a qualified person(s). Tensile/compressive load ratings shall be established by design verification or validation. Pressure performance and defined operational capabilities shall be established by validation.

The supplier/manufacturer shall establish the following ratings either through documented field history and/or verification (V3-TP) or by validation testing (V2-TP, V1-TP):

a) performance rating envelope per Annex D;

b) absolute internal (bore) pressure (if applicable);

c) absolute external (annulus) pressure (if applicable);

d) maximum differential pressure(s) across element from above and below (with minimum setting load/pressure);

e) maximum differential pressure(s) across packer body (plugged condition);

f) other pressure restrictions applicable to the packer;

Table E.1—Packer Validation Testing Coverage

<table>
<tr><th colspan="2">Summary of Packer Design Validation Grade Testing Requirements</th></tr>
<tr><td>Tools to be validated</td><td>— Well testing packers
— Separate hold-down devices (if applicable)
— Separate bypass devices (if applicable)</td></tr>
<tr><td>V3-TP</td><td>Packer designs shall comply with the requirements of E.4 (supplier/manufacturer-defined requirements).</td></tr>
<tr><td rowspan="6">V2-TP</td><td>Packer shall comply with the requirements of E.5. Prescribed pressure/temperature event sequence lasting a minimum of 5 days at elevated temperature to validate the following.</td></tr>
<tr><td>Internal Pressure—Validation of internal differential pressure rating. Tested to 105 % of the rated pressure at the rated maximum temperature.</td></tr>
<tr><td>External Pressure—Validation of external differential pressure rating. Tested to 105 % of the rated pressure at the rated maximum temperature.</td></tr>
<tr><td>Absolute Pressure—Validation of absolute pressure rating. Tested to 105 % of rated pressure at rated maximum temperature.</td></tr>
<tr><td>Temperature Drop—Validation of a packer's pressure integrity and functionality after a drop from its maximum rated temperature such as that which would occur as the result of stimulation pumping. The temperature drop from the maximum rated temperature and the associated pressure reversal are to be included in the packer's specification.</td></tr>
<tr><td>Drift Test—Validation that the ID of the packer can pass a drift bar of a prescribed diameter.</td></tr>
<tr><td>V1-TP</td><td>Packer shall comply with the V2 validation testing requirements of E.5 and an internal (tubing-side) pressure test with gas per E.8 to validate the packer's ability to seal with gas up to the internal pressure rating. (Tested at rated maximum temperature and 105 % of rated differential pressure applied to tubing and lower side of the packer element and no OD pressure above the element.)</td></tr>
</table>

g) maximum rated temperature;

h) temperature drop from maximum rated temperature;

i) minimum operating temperature of the packer;

j) tensile/compressive ratings of slip/anchoring systems in the hardest rated casing grade;

k) applicable casing size and weight(s);

l) tensile/compressive load ratings of the packer body (may be established by verification);

m) other operational/pressure/environmental limitations applicable to the packer (such as pressure testing limits at low temperature, function testing at low temperature, or the ability to maintain integrity at low subsea temperatures while RIH).

NOTE Loading on packers due to transient pressure and structural waves initiated by perforating is a known phenomenon. There are no currently known practical validation techniques that can effectively replicate this loading. Numerical analysis techniques may be used to assess packer performance under specific environmental conditions and are not included in this annex.

E.3 Design Validation Overview

The supplier/manufacturer shall document all parameters and results of the evaluations to demonstrate conformance to the selected validation grade. The supplier/manufacturer shall have documented testing procedures for performance of the defined testing steps. A packer assembly shall successfully perform all of the defined test steps of each set of validation tests for the selected validation grade level. The packer assembly may be redressed for any special feature testing; however, repair or redress during a contiguous testing sequence requires a restart of the complete testing sequence.

The base validation shall be selected from the testing procedures shown in Table E.1. When forces and/or movements applied to the packer from push/pull actuators inside of the test vessel are affected by applied test pressure(s) in a way not representative of test step requirements, corrective adjustments may be made to the testing criteria. Procedure changes shall be justified, documented, and approved by a qualified person other than the preparer of the procedure.

The supplier/manufacturer shall validate the minimum operating temperature with either a subassembly test or a complete packer system validation.

The validation of nonmetallic seals in a packer system, excluding the packer element, shall conform to the requirements of Annex A. Validation requirements for alternate packer elements are included in E.7. Design changes to validated packer designs shall conform to the requirements of 6.10.

Changes to the packer element sealing system (consisting of elastomeric elements and anti-extrusion devices) shall require revalidation testing. If new ratings for the packer element sealing system exceed the validated pressure-temperature envelope, a full system validation shall be performed. If new ratings for the packer element sealing system remain within the validated pressure-temperature envelope, the sealing system may be revalidated to the packer qualification profile by a subassembly test, providing the test setup represents the behavior of the complete packer system as determined by a qualified person, as per E.7. Alternately, a full packer validation shall be performed.

E.4 V3-TP Validation Level Requirements

To address legacy designs, results from separate tests and/or documented field history performance may be combined to validate the packer's ratings. The supplier/manufacturer shall demonstrate and document that the validation testing results and/or documented field history meet the requirements of the packer's ratings. Ratings shall be documented and approved by a qualified person other than the qualified person who performed the testing.

Test(s) results and/or documented field history performance shall be compiled into a report that establishes the packer's performance capabilities and ratings. Test results and procedures shall be documented to an adequate amount of detail to allow the testing process to be replicated.

Design changes to V3-TP packers shall conform to the requirements of 6.10.

Following the effective date of this specification, new packer designs that conform to this specification shall meet the requirements of V2-TP or V1-TP. Legacy designs that comply with V3-TP requirements of this specification may be validated to comply with V2-TP or V1-TP, provided all requirements of E.5 and/or E.8 are performed as applicable.

E.5 V2-TP Validation Level Overview

E.5.1 General

V2-TP validation requires that a packer be exposed to a standard set of pressure/temperature events that represent an environment commonly experienced during well testing with liquid as the test medium. This sequence of events is expressed in a validation profile test sequence. Figure E.1 is a graphical illustration of these conditions.

The overview of the validation profile test sequence described in E.5 includes temperatures, pressures, and times. Key pressure points are illustrated by labels 1 to 12 in Figure E.1.

The baseline hydrostatic pressure L0 shown in Figure E.1 is a minimum hydrostatic pressure during the validation test, and it shall be no less than 50 % of the packer's absolute pressure rating. A different baseline hydrostatic pressure can be established at any point in the test, provided it is never less than 50 % of the absolute rating.

— Labels 1 and 2 simulate the packer's preparation and running into the well.

— Label 3 is a validation of the packer's absolute pressure rating.

— Label 4 is a validation of the packer's absolute and differential ratings (internal and external) at temperature, performed two times.

— Labels 5 and 6 simulate drawdown and buildup events where the annulus pressure is greater than the packer's internal pressure.

— Label 7 simulates an injection event, where the packer experiences a decrease in temperature with a corresponding pressure reversal.

— Label 8 simulates a screen-out, where internal pressure further increases. This is intended to validate the packer's capabilities to continue to function with a temperature excursion.

— Labels 9 and 10 represent the final flow period.

— Labels 11 and 12 indicate a simulation of end of job conditions where well kill operations could again require full differential pressure and/or absolute pressure capabilities and valve operations in addition to the effects of pulling out of hole.

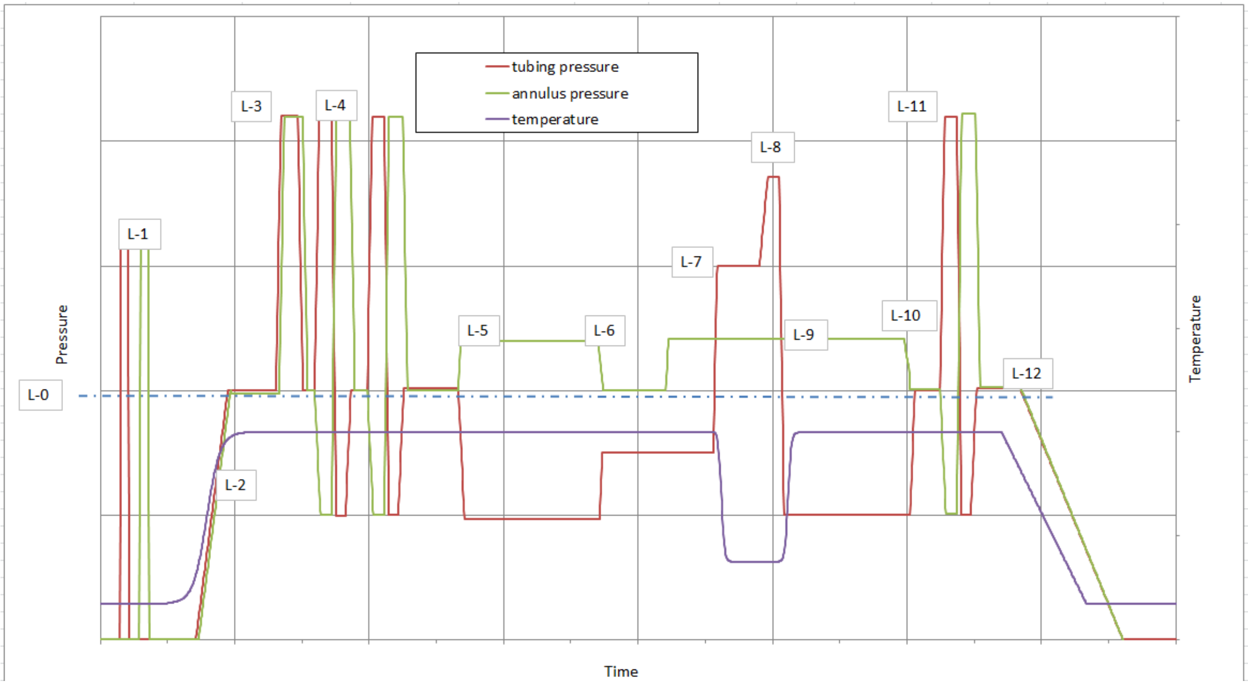
An absolute pressure rating shall be validated as prescribed in the validation profile test sequences in E.5.3 and E.6.2 as applicable. If a separate verified absolute pressure rating (as opposed to the validated rating) is established, the verified absolute pressure rating shall conform to the requirements of 6.6. The packer's datasheet shall clearly distinguish between validated and verified absolute pressure ratings.

NOTE An example of a verified absolute pressure rating is given by a packer containing no atmospheric chambers and supplementary laboratory test data indicating that the properties of the elastomers (including packer elements) are not adversely affected by hydrostatic pressure in the range between the validated and verified pressure.

The design verification of nonmetallic element(s) at higher absolute pressure shall include subassembly testing or be supported by successful V2-TP validation of the same nonmetallic compound at the higher absolute pressure on other packer assemblies having the same seal design. For subassembly testing, the reporting provisions of A.3.6.6 shall apply.

Any low temperature performance rating not tested during the validation profile test sequence in E.5.3 and E.6.2 as applicable may be established through separate testing. Such testing and results shall conform to the supplier/manufacturer's documented procedures and acceptance criteria. Such rating limits may include, but are not limited to, pressure testing limits at low temperature, function testing at low temperature, or the ability to maintain integrity at low subsea temperatures while RIH.

The supplier/manufacturer shall have documented procedures to perform all testing. The results shall be approved, and applicable ratings shall be established, by a qualified person.



Labels

L-1	Differential pressure test prior to RIH
L-2	Heating and pressurization of tools while RIH
L-3	Absolute pressure test at temperature
L-4	Absolute/differential pressure testing at temperature
L-5	Flowing the well
L-6	Shut in well for pressure buildup
L-7	Start injection for stimulation job, temperature drop due to cold injection fluid
L-8	Screen-out during injection
L-9	Flowing the well while temperature returns to maximum
L-10	Shut in well for pressure buildup
L-11	Final differential pressure test after temperature cycle
L-12	Pulling of out hole (POOH), pressure and temperature decreasing

Figure E.1—General Representation of Validation Profile Test Sequence

E.5.2 V2-TP Validation Level Requirements

V2-TP validation of a packer for a single casing weight is accomplished by performing a minimum 5-day test at the maximum rated temperature on a full packer assembly in accordance with E.5.3.

When a packer design is designated for a single casing ID (not a range), a single validation test may be performed at the nominal casing ID plus the maximum tolerance per API Specification 5CT.

V2-TP validation of a packer over a range of casing weights for a nominal casing size is accomplished by performing a minimum 5-day test on a full packer assembly in accordance with E.5.3 to simulate the lightest weight casing for a nominal casing size (largest ID). To extend the casing weight coverage, it is also required to perform an abbreviated 2-day test simulating the heaviest weight casing for a nominal casing size (smallest ID) per E.6.2. This abbreviated test may be performed in a fixture, rather than on a full packer assembly, in accordance with the provisions of E.6.

The test fixture material shall correspond to the highest casing grade for which the packer is rated. The test fixture OD is not required to be representative of the actual casing OD, nor does it necessarily represent the presence of, or lack of, external support from a cement sheath.

The supplier/manufacturer shall adhere to the following test parameters and criteria for conformance to validation level V2-TP when testing a complete packer assembly.

a) All testing shall be performed in the order prescribed as per E.5.3 and E.6.2, as applicable to the limits defined, on calibrated equipment per 7.5.1, by qualified personnel, and all testing results and commentary shall become a portion of the packer's design records.

b) The testing steps represented in the validation profile test sequence in E.5.3 and E.6.2 as applicable shall be conducted over the minimum number of days prescribed at the specified elevated temperature, exclusive of initial heating and final cooldown.

c) All applied temperatures, pressures, loads, and actions shall be measured and recorded on time-based equipment.

d) During temperature transitions, pressure shall be managed in accordance with supplier/manufacturer facility capabilities. Previously prescribed conditions shall be reestablished before the next prescribed hold period.

e) Prescribed conditions (pressure and/or temperature) shall continue until a change in those conditions is specified by a subsequent test step.

f) For packers using a rupture disc or shear device, and where it is not possible to achieve maximum test pressures required for validation testing without exceeding the rupture or shear device value, it is permissible to perform a separate test to validate the maximum pressure ratings with activation method disabled. This separate test shall be performed at the packer's maximum rated temperature, but the test does not require repeating the full validation profile test sequence. A qualified person shall document the justification for utilizing the alternate test method, procedures, and acceptance criteria.

g) The packer shall be assembled and installed into the test fixture, utilizing supplier/manufacturer documented procedures.

h) Setting force shall be the minimum recommended (±10 %).

i) Packers without an integral anchoring device(s) may be restrained by the test fixture to prevent movement in the unanchored direction(s).

j) Test to a minimum of 5 % above the maximum rated differential pressure and to a minimum of 5 % above the maximum validated absolute pressure rating.

k) Validation of packer axial load capability of slip/anchoring systems can be performed independently of pressure tests. If axial loads are applied in an independent test, the applied axial loads shall include the effective contribution from any pressure effects. A qualified person shall establish the validity of conducting such tests separately and their combination into an effective operating envelope. Other axial load capabilities not related to the slip/anchoring system may be established by design verification in accordance with 6.3.2.1.

l) Packers having shear-release features shall be tested to a minimum of 5 % above their maximum rated shear load. For safety, a shear device shall be utilized that can adequately withstand the maximum applied test load.

m) Each packer that includes a pressure-retaining chamber (such as a hydraulic or gas chamber used in the operation of the packer and/or other similar pressure-retaining chamber) that is not tested to its maximum rating during the validation or functional tests shall be pressure tested by a qualified person(s) at its maximum rated pressure at room temperature using supplier/manufacturer documented procedures and acceptance criteria.

n) Following each successful validation test, the packer shall be disassembled and inspected to the supplier/manufacturer's documented requirements. Observations shall be documented in the respective test results report.

E.5.3 V2-TP Validation Profile Test Sequence Using Full Packer Assembly (5-day Minimum)

Validation testing to conform to V2-TP shall include the following.

1) Perform internal and external pressure test with liquid to a minimum of 105 % of maximum rated differential pressure at ambient temperature or a minimum temperature specified by the supplier/manufacturer at which the packer can withstand 105 % of rated differential pressure. Relieve pressure after each pressure test.

2) Increase test vessel temperature up to the maximum rated temperature of the packer while managing bore and external pressure increase up to 50 % of the absolute pressure rating. Maintain the packer at its maximum rated temperature through Step 14.

3) Set the packer using supplier/manufacturer's defined procedure using the minimum setting load. Set the packer at a pressure not less than 50 % of the absolute pressure rating.

4) Increase bore and external pressure to 105 % of the maximum absolute pressure rating. Hold until the vessel pressure is stable for a minimum of 1 hour.

5) Reduce and stabilize bore and external pressures to a value not less than 50 % of the maximum absolute pressure rating.

6) Increase and stabilize the bore pressure to at least 105 % of the maximum absolute pressure rating. While maintaining bore pressure, adjust and stabilize external pressure to achieve 105 % of the differential pressure rating. Hold and record per the acceptance criteria in E.9.2.2. (Simulating pressure test from below packer.)

7) Increase and stabilize the external pressure to at least 105 % of the maximum absolute pressure rating. While maintaining external pressure, adjust and stabilize bore pressure to achieve 105 % of the differential pressure rating. Hold and record per the acceptance criteria in E.9.2.2. (Simulating pressure test from above packer.) Step 7 may be performed before Step 6.

8) Adjust and stabilize the bore and external pressures to a value not less than 50 % of the absolute pressure rating.

9) Repeat Steps 6 to 8 one additional time.

10) Increase external pressure by at least 1500 psi and stabilize. (Simulating opening tester valve.)

11) Reduce and stabilize the bore pressure to achieve 50 % of the rated differential pressure (annulus high), and hold for a minimum of 24 hours. (Simulating drawdown period.)

12) Reduce and stabilize the external pressure to a value not less than 50 % of the absolute pressure rating. Increase bore pressure and stabilize to achieve a minimum of 20 % of differential pressure rating (annulus high), and hold the pressures for a minimum of 12 hours. (Simulating buildup period.)

13) Increase external pressure by at least 1500 psi and stabilize. (Simulating opening tester valve as a prelude to stimulation.)

14) Increase and stabilize the bore pressure to achieve a minimum of 20 % of the differential pressure rating (tubing high), and hold for a minimum of 1 hour. (Pressure reversal from stimulation pumping.)

15) Reduce and stabilize the temperature that is equal to the maximum rated temperature minus the rated temperature drop. The input of heat to extend the cooldown period shall not be allowed. Hold for a minimum of 30 minutes. (Temperature drop due to stimulation pumping.)

16) Increase and stabilize the bore pressure to achieve a minimum of a 50 % of the differential rating (tubing high). Hold for a minimum of 1 hour. (Representing screen-out.)

17) Reduce and stabilize the bore pressure to achieve a minimum of 50 % of the rated differential pressure (annulus high). Hold for a minimum of 1 hour. (Representing final flow period after stimulation.)

18) Increase the temperature to at or above the packer's maximum temperature rating. Once temperature and pressure have stabilized, hold for a minimum of 12 hours. (Representing temperature rise during final flow period.)

19) Adjust and stabilize the bore pressure and external pressure to a value not less than 50 % of the absolute pressure rating. Hold for a minimum of 30 minutes.

20) Repeat Steps 6 through 8 one time. These steps shall occur after a minimum of 4.5 days in the test facility, exclusive of the initial heat-up period.

21) Cool down the test packer and vessel (or start V1-TP validation test).

22) Remove packer from test vessel and perform drift test per E.9.4.

23) Disassemble and inspect the tested packer according to the supplier/manufacturer's procedure and acceptance criteria.

The inability to complete any portion of the testing within the defined limits shall be considered a test failure, and a complete retest is required.

E.6 Casing Range Extension Validation Requirements

E.6.1 General

Packers shall be validated within a casing internal diameter corresponding to both the maximum and minimum ID over the intended nominal casing size and weight range. A rating for a range of casing weights can be validated by the combination of full packer assembly validation profile test in an ID representing the lightest casing weight for the intended nominal casing range per E.5.3 plus an additional validation test conducted in a fixture having an ID representing a defined heavier casing weight per E.6.2.

Different nominal casing sizes having an ID that falls within the validated range can be considered as validated. When validating over a nominal casing size and weight range, changes in packer designs shall be limited to the packer element diameter and/or gauge rings only, while a documented and justifiably equivalent radial casing extrusion gap shall be maintained. Any other changes in design require a full packer assembly validation test.

The validation for the packer design in the minimum ID of the casing size and weight range (heaviest casing weight) may be performed with an abbreviated validation profile test (2-day minimum) using a packer element test fixture representing the packer element sealing system in the smallest nominal casing ID minus the maximum tolerance per API Specification 5CT.

In addition, slip load testing shall be performed in the largest and smallest casing IDs corresponding to the intended casing size and weight range and may be performed with a subassembly of the full packer assembly.

The test sequence to extend the packer's rating range in conformance to validation level V2-TP is defined in E.6.2. The test sequence to extend the packer's rating range in conformance to validation level V1-TP is specified in E.8.3.

The packer element test fixture shall represent all pertinent aspects of the previously validated packer assembly, associated fits/finishes, tolerances, and setting/loading forces.

a) The procedure for element validation in a fixture with the new casing weight shall expose the packer element subassembly to the same pressure, temperature, and operational cycles as the original tool V2-TP validation procedure but with a reduced time duration of 2 days (minimum) exclusive of initial heating and final cooldown per E.6.2.

b) Changes in packer element diameter and/or gauge rings may be made to adjust to the heavier casing weight provided that the resulting radial extrusion gap (radial distance gauge ring OD to nominal casing ID) remains less than or equal to (within supplier/manufacturer's tolerances) the extrusion gap of the fully validated packer design that the casing extension validation is based on.

c) The packer element system in the validated casing weight is to be rated for a maximum temperature and/or pressure that is not greater than that of the fully validated packer assembly.

d) When a new lower temperature limit after a temperature drop is to be established, this value shall not be less than the minimum temperature at which the packer assembly can withstand 105 % of its differential pressure rating.

e) The packer validation procedure for the new casing weight shall be prepared by a qualified person and approved by a second qualified person. The procedures and validation results shall be included in the tool's design documentation.

f) All testing shall be performed in the order prescribed, to the limits defined, on calibrated equipment, by qualified personnel and all testing results, and commentary shall become a portion of the packer's design records.

g) All applied temperatures, pressures, loads, and actions shall be measured and recorded on time-based equipment.

E.6.2 Abbreviated V2-TP Validation Profile Test for Range Extension to Heaviest Weight Casing Using a Fixture (2-day Minimum)

When a packer is to be V2-TP validated over a range of casing weights corresponding to a nominal casing size, a full packer assembly shall be used to validate the heaviest weight casing (largest ID) per C.5.2. V2-TP validation of the packer in the heaviest weight casing of the same nominal casing size (smallest ID) can be performed in a test fixture as follows.

1) Assemble packer element sealing system and gauge rings into test fixture.

2) Increase test fixture temperature up to the maximum rated temperature of the packer, while managing bore and external (annulus) pressure and while increasing both up to 50 % of the absolute pressure rating. Maintain the packer elements at maximum rated temperature through Step 14.

3) Set packer elements using supplier/manufacturer's defined procedure using the minimum setting load. Set the packer elements at a pressure not less than 50 % of the absolute pressure rating.

4) Increase bore and external (annulus) pressure to 105 % of the absolute pressure rating. Hold until the fixture pressure is stable for a minimum of 1 hour.

5) Reduce and stabilize bore and external (annulus) pressures to a value not less than 50 % of the absolute pressure rating.

6) Increase and stabilize the bore pressure to at least 105 % of the absolute pressure rating. While maintaining bore pressure, adjust and stabilize external (annulus) pressure to achieve 105 % of the differential pressure rating. Hold and record per the acceptance criteria in E.9.2.2. (Simulating a pressure test from below the packer element.)

7) Increase and stabilize the external (annulus) pressure to at least 105 % of the absolute pressure rating. While maintaining external (annulus) pressure, adjust and stabilize bore pressure to achieve 105 % of the differential pressure rating. Hold and record per the acceptance criteria in E.9.2.2. (Simulating pressure test from above packer elements.)

8) Adjust and stabilize the bore and external (annulus) pressures to a value not less than 50 % of the absolute pressure rating.

9) Repeat Steps 6 to 8 one additional time.

10) Increase external (annulus) pressure by at least 1500 psi and stabilize. (Simulating opening tester valve.)

11) Reduce and stabilize the bore pressure to achieve a minimum of 50 % of the rated differential pressure (annulus high), and hold for a minimum of 6 hours. (Simulating abbreviated drawdown.)

12) Reduce and stabilize the external (annulus) pressure to a value not less than 50 % of the absolute pressure rating. Increase bore pressure and stabilize to achieve a minimum of 20 % of differential pressure rating (annulus high), and hold the pressures for a minimum of 3 hours. (Simulating abbreviated buildup.)

13) Increase external (annulus) pressure by at least 1500 psi and stabilize. (Simulating opening the tester valve as a prelude to stimulation.)

14) Increase and stabilize the bore pressure to achieve a minimum of 20 % of the differential pressure rating (tubing high), and hold for a minimum of 1 hour. (Pressure reversal from stimulation pumping.)

15) Reduce and stabilize the temperature to a value that is equal to the maximum rated temperature minus the rated temperature drop. The input of heat to extend the cooldown period shall not be allowed. Hold for a minimum of 30 minutes. (Temperature drop due to stimulation pumping.)

16) Increase and stabilize the bore pressure to achieve a minimum of a 50 % of the differential rating (tubing high). Hold for a minimum of 1 hour. (Representing screen-out.)

17) Reduce and stabilize the bore pressure to achieve a minimum of 50 % of the rated differential pressure (annulus high). Hold for a minimum of 1 hour. (Representing final flow period after stimulation.)

18) Increase the temperature to at or above the packer's maximum temperature rating. Once temperature and pressure have stabilized, hold for a minimum of 3 hours. (Representing temperature rise during final flow period.)

19) Adjust and stabilize the bore pressure and external (annulus) pressure to a value not less than 50 % of the absolute pressure rating. Hold for a minimum of 30 minutes.

20) Repeat Steps 6 through 8 one time. These steps shall occur after a minimum of 1.5 days in the test fixture, exclusive of the initial heat-up period.

21) Cool down the test fixture.

22) Remove packer elements from test fixture.

23) Disassemble and record condition of the elements and test fixture according to the supplier/manufacturer's procedure.

24) Successful completion of this process is documented conformance to the pressure integrity leakage criteria in E.9.2.2.

The inability to complete any portion of the testing within the defined limits shall be considered a test failure, and a complete retest is required.

E.7 Alternative Packer Element Compound Validation Requirements

E.7.1 General

For packer assemblies that have successfully completed V1-TP or V2-TP validation testing, alternative packer element compounds can be utilized when all requirements of this section are met. A change in supplier of the same compound or a change in compound or durometer can be substituted and validated by utilizing a test fixture instead of performing a complete packer validation test.

Alternative validation of seal compounds shall be performed within the following limits.

a) The test fixture must represent all pertinent aspects of the packer element sealing system (consisting of elastomeric elements and anti-extrusion devices), associated fits/finishes, tolerances, previously validated casing size, and setting/loading forces.

b) The packer element is to be rated for a temperature and/or pressure that is not greater than that of the previously validated packer assembly.

c) If the new intended minimum temperature at which the packer can withstand 105 % of its differential pressure rating is less than the value determined from a validation test on a full packer assembly, this value shall be validated on a fully assembled packer using the procedure in A.3.6.2.1. If this value is greater than or equal to that determined from a prior validation test on a full tool assembly, the value shall be validated using either the procedure in A.3.6.2.1 or by using a test fixture that represents the technical requirements of the packer design and installation.

d) When a new lower temperature limit is to be established after a temperature drop, this value shall not be less than the minimum temperature at which the packer can withstand 105 % of its differential pressure rating.

e) The procedure for packer element testing in the fixture shall expose the seal configuration to the same pressure, temperature, operational cycles, and time duration as the minimum 5-day full packer assembly validation profile test procedure, as per E.5.3 for V2-TP validation. V1-TP validation of alternative packer element compounds shall be allowed per E.8 following successful V2-TP validation per this paragraph.

f) The potential effect of any movement on packer element performance such as speed or sequence shall be accurately represented in the test fixture.

g) The packer element validation procedure and acceptance criteria shall be prepared by a qualified person and approved by a second qualified person. The procedures and validation results shall be included in the packer's design records.

E.7.2 Alternative Packer Element Compound Validation Test Sequence in a Fixture

Testing shall consist of the following.

1) Testing shall conform to the requirements of E.1.

2) Perform all steps defined in E.5.3 (liquid test medium).

3) For V1-TP packers, also perform seal compound validation test in a fixture as per G.8.2, with gas as the test medium.

4) The acceptance criteria shall be per E.9.

E.8 V1-TP Validation Level Requirements

E.8.1 General

V1-TP validation requires that a packer first pass all the tests associated with V2-TP validation per E.5 (and E.6 for a casing weight range, if applicable). Additionally, the packer shall pass V1-TP gas testing as follows.

V1-TP validation of a packer for a single casing weight is accomplished by performing a bore pressure test on a full packer assembly with gas as the test medium per E.8.2.

V1-TP validation for over a range of casing weights that correspond to a nominal casing size is accomplished by performing a bore pressure test on a full packer assembly with gas as the test medium per E.8.2, simulating the lightest weight casing for a nominal casing size (largest ID) plus an additional validation test conducted in a fixture simulating the heaviest weight casing for a nominal casing size (smallest ID) per E.8.3.

Test fixtures shall have an ID that is not less than the maximum casing ID, accounting for tolerance per API Specification 5CT. The test fixture material shall correspond to the highest casing grade for which the packer is specified. The test fixture OD is not required to be representative of the actual casing OD, nor does it necessarily represent external support from a cement sheath.

Testing can be performed independently on a newly redressed packer or as a continuation of the V2-TP validation profile test with the packer remaining set in the V2-TP fixture and at temperature.

The packer can be initially set in either liquid or in pressurized gas. If the packer is initially set in liquid, or as a continuation of a V2-TP test, a means must be available to remove all liquid from the bore side prior to performing the gas test.

Following each successful validation test, the packer shall be disassembled and inspected to the supplier/manufacturer's documented requirements. Observations shall be documented in the respective test results report.

E.8.2 V1-TP Validation Profile Test Sequence Using Full Packer Assembly

Following the successful completion of the V2-TP validation level requirements, the V1-TP testing shall consist of the following steps, if not performed as a continuation of the V2-TP validation profile test. If V1-TP testing is continuing from a V2-TP test, begin at Step 4.

1) Perform FAT of packer assembly per supplier/manufacturer procedures prior to heating the test vessel.

2) Increase test vessel temperature up to the maximum rated temperature of the packer.

3) Set packer using supplier/manufacturer's defined procedure in liquid or gas using the minimum rated setting load. Set the packer at 50 % of the maximum hydrostatic rating.

4) If the packer was set in liquid, drain all liquid from anchored packer-casing assembly before introducing the gas testing medium. This may require temporary removal of the anchored packer-casing assembly from the test vessel and an inadvertent additional temperature cycle. If the packer is set in gas, proceed to Step 5.

5) At rated temperature, adjust bore and external (annulus) pressures (now with gas test medium) to the maximum differential pressure rating with external (annulus) bled to zero. Continue to hold until the pressure is stable per the gas testing acceptance criteria in E.9.2.3.

6) Terminate test. Cool down test packer and vessel.

7) Remove packer from test vessel and perform drift test per E.9.4.

8) Disassemble and inspect the tested packer according to the supplier/manufacturer's procedure and acceptance criteria.

The inability to complete any portion of the testing within the defined limits shall be considered a test failure and a complete V1-TP retest is required.

E.8.3 V1-TP Validation Using an Element Fixture (Heaviest Casing Weight in a Range)

When validating a packer over a range of casing weights corresponding to a nominal casing size, the heaviest casing weight (smallest diameter casing) may be performed in an element fixture using gas as the test medium as follows.

1) Install packer element into fixture.

2) Increase fixture temperature up to the maximum rated temperature of the packer.

3) Increase fixture gas pressure to 50 % of the maximum hydrostatic rating.

4) Compress element to the minimum rated setting load using supplier/manufacturer's defined procedure for the fixture.

5) At rated temperature, adjust bore and external (annulus) pressures to maximum differential pressure rating with external (annulus) bled to zero. Continue to hold until the pressure is stable per the gas testing acceptance criteria in E.9.2.3.

6) Repeat Step 5.

7) Terminate test. Cool down test fixture and vessel.

8) Remove element from the fixture, inspect, and record condition.

The inability to complete any portion of the testing within the defined limits shall be considered a test failure, and a complete retest is required.

E.9 Design Validation Testing Acceptance Criteria

E.9.1 General

The acceptance criteria in this section shall apply to all pressure integrity testing, including special feature tests. Each packer design shall conform to the requirements and acceptance criteria of this section at each numbered test step where acceptance criteria are required. Failure to conform to the requirements is cause to stop the testing and restart from the beginning of the validation testing process.

E.9.2 Pressure Integrity Tests

E.9.2.1 General

In this specification, leakage is considered to be a measureable change in pressure over a 15-minute hold period, as defined in E.9.2.2 and E.9.2.3. Any visible leakage, internally or externally, is cause for failure.

E.9.2.2 Pressure Integrity Tests with Liquid

For V2-TP testing, testing is performed with a liquid. Each tool shall be hydrostatically pressure tested at the defined pressure(s) and associated defined temperature(s) using supplier/manufacturer procedures. Test medium shall be water, with or without additives, or hydraulic oil. Liquid shall be free from particulate matter and/or other material that have the potential of plugging small leaks. All fluids used shall be defined and documented in the test report.

The pressure test acceptance criteria is a maximum of 1 % change in the applied pressure, with a decreasing rate of change, over a period of 15 minutes after sufficient time has been allowed for stabilization.

E.9.2.3 Pressure Tests with Gas

For V1-TP testing, testing is performed with nitrogen or other inert gas. Gas leak rate acceptance criteria is less than 20 cm^3 of gas at atmospheric pressure over a 15-minute hold period after sufficient time has been allowed for stabilization after applying the rated differential pressure. Additionally, the volume accumulated during the second $7^1/2$ minutes of the hold period shall not exceed the volume accumulated in the first $7^1/2$ minutes of the hold period. The leak rate and total leakage shall be recorded in the test report.

E.9.3 Special Features Test(s)

Special feature and/or claimed capability(s) shall be validated to its rated limits in accordance with the supplier/manufacturer's documented test procedures. These validation tests may be incorporated into the existing sequence of design validation, providing they do not cause operational limitations to the packer. Pressure integrity tests results shall conform to the acceptance criteria herein; all other test results shall conform to the supplier/manufacturer's documented acceptance criteria.

E.9.4 Drifting Requirements and Acceptance Criteria

After all functional testing steps are complete, perform a drift test using a drift bar having a minimum length of 42 in. (±0.5 in.) at the specified diameter. The drift bar shall have a diameter no less than the nominal packer inner diameter minus 0.125 in. inclusive of diametral and straightness tolerances. The drift bar shall pass completely through the packer in both directions where feasible, and it shall not require a force greater than the weight of the bar. Each drift bar shall be permanently marked with a unique identifier and the measured drift bar dimensions. The drift bar unique identifier shall be recorded in the validation test report.

E.9.5 Test Reporting

A final report of the design validations shall be prepared by a qualified person and approved by a qualified person other than the person who prepared the report. The test report becomes a portion of the packer's design documentation. The report shall as a minimum include:

a) testing location(s), date, and person performing the testing;

b) the packer's unique identification, such as part number and serial number;

c) testing procedures used and records required by those procedures;

d) detailed results, discussion of conformance to acceptance criteria, and post-test recommendations if applicable;

e) approval indications such as signatures.

Annex F
(normative)

Electronic and Electrical Components, Subcomponents, and Systems Requirements

F.1 General

This annex covers the requirements for electronic and electrical components, subcomponents, and systems that provide electronic monitoring, electrical power sources, measuring, or signal processing capabilities (hereafter called products). Each product shall have documented process(es) that validate the design. Thereafter each copy of the design that is manufactured is considered validated throughout the specified operating range. The performance of each product or system shall conform to the requirements defined by the supplier/manufacturer. This coverage also includes all connectors and cabling to internal and external conduits. However, this coverage is limited to the physical constraints of the downhole tool, and external conduit(s) are not included.

Ratings for each of the claimed parameters of the product's operation, including life cycle, shall be explicitly defined and supported by technical documentation that includes successful validation testing and/or verification to defined acceptance criteria. All testing and test results shall be evaluated and approved by a qualified person other than the qualified person who created or tested the design.

The mechanical hardware and body sealing components are covered by other portions of this standard.

F.2 Design Controls and Rated Limits

The supplier/manufacturer shall establish geometrical dimensions, localized and overall temperature limitations, vibration/shock resistance, and the operational capabilities/limitations necessary to meet the product's stated operational capabilities in the specified environment and conform to the requirements of this standard. The effects of temperature, environment, material properties, and combined loading on all materials and subcomponents shall be considered in establishing the rated capabilities and durability of the final product.

The mechanical and electronic/electrical design shall take into account the effects of externally and internally induced loading. Designs shall take into consideration the effects of temperature, pressure, environmental chemistry, and vibration/shock on all components. The upper and lower temperature limits shall be established by system level validation testing. The design shall take into account the effects of exposure to and/or retained fluid(s) supplied in the functional specification and any other chemicals routinely encountered in oil and gas production. Specialized and/or intermittent conditions such as transport and surface testing shall be considered in the design verifications and validations of each product. Products conforming to this standard shall be manufactured to drawings, requirements, and specifications that contain no substantive changes from those of the product that passed the applicable validation testing. A new validation test conforming to manufacturer/supplier's procedure(s) is required for new components.

The rated limits of the design shall be stated for all operational parameters and can include the cumulative effects of time and temperature based upon industry-accepted or other demonstrated temperature-dependence relationships. All rated limits shall be supported with approved validation and verification successful testing results.

F.3 Material Controls

Materials for each subcomponent and component shall be stated by the supplier/manufacturer and shall be suitable for the operational needs and environmental conditions defined in the functional specification. The supplier/manufacturer shall have documented specifications for all materials, and materials shall comply with these specifications. The change in a component specification shall require a new validation test to prove the performance of that component design.

The supplier/manufacturer shall have documented procedures that verify the material used is suitable in the configuration, environment, and application of the functional specification. These procedures shall, as a minimum, consider the combination of electrical capacity, insulation qualities, pressure, temperature, geometric design, operational properties, application, and environment.

Material substitutions or processes that differ from those used in the validation of tested products will require revalidation since material and/or process changes can subtly and critically affect high-temperature electronics. The 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 standard. Material substitutions require approval by a qualified person, and the supporting documentation and validation testing shall be incorporated into the design documentation.

F.4 Design Validation

Design validation testing shall be performed on each size, type, and model of the product to the rated limits defined by the supplier/manufacturer, including life cycle. Validation testing shall be performed by a qualified person on calibrated equipment and the testing results approved by a second qualified person. Successful completion of the documented validation testing process within the defined acceptance criteria shall qualify that design for use.

F.5 Design Documentation

Documentation of designs for each size, type, and model of product shall include design requirements, functional and technical specifications, methods, assumptions, comparison with previous designs (where directly applicable), design calculations, design reviews, and validation evaluation/testing procedures/acceptance criteria and their approved results. Design requirements shall include those operational loads, materials, environmental, and other pertinent requirements upon which the design is based. Documentation used for final acceptance shall be available for audit by the user/purchaser.

F.6 Functional Testing

Each product manufactured shall be tested by a qualified person to a documented procedure that corresponds to the stated functionality of the product. This testing shall have defined acceptance criteria and shall be completed acceptably and the documented results approved by a qualified person prior to the product being put into service.

F.7 Repair/Rebuild Requirements

Product life cycle capabilities/limitations, repair controls, and limitations shall be stated by the supplier/manufacturer and include documented procedures for periodic evaluation, repair, and maintenance of all products covered by this standard. At the conclusion of each process, the product shall be validated as performing to the limits defined in the functional requirements and to the supplier/manufacturer's requirements.

Replacement components and subassemblies shall be evaluated and perform to the requirements of the component they replace. Repaired, rebuilt, or redressed systems shall pass a functional test no less stringent than that used at the time of the original manufacture. The supplier/manufacturer shall conform to a documented testing program for each of the electronic/electrical capabilities and features to ensure the product performs as designed. The quality controls and restrictions applied to the repaired/redressed product shall be no less stringent than those in place at the time of the original manufacture. Each new or replaced product shall be marked with a traceable unique identifier that is recorded as part of the product's maintenance documentation.

Annex G
(normative)

Testing Surface Safety Valve Requirements

G.1 General

This annex provides the requirements for the design, materials, validation testing, and functional testing of each TSSV design and manufactured product.

The TSSV is designed to serve as a surface closure device during a well test or well intervention. The TSSV is deployed in the well testing string and is positioned inside the surface BOP with the pipe rams closed across its ported slick joint (see G.4). These valves shall have a single or dual normally closed closure mechanism with positive pressure pump-through capability at all times. The TSSV is operated by a hydraulic control line from the surface. Positive control line pressure is needed to keep the valve open, while any loss of control pressure will result in the valve closing. The closure mechanism may have enhanced cutting capabilities for coiled tubing and/or wireline. Depending on the valve's design, applied boost pressure may be required to cut coiled tubing or wireline if it is present in the bore.

The valve design shall have chemical injection capability below the closure mechanism and/or between closure mechanisms if the design has a dual closure system. The chemical injection circuit shall include dual nonreturn valves (NRVs) integral to the body of the valve. The NRV may be housed integral to the ported slick joint only if directly connected to the valve body.

Sections 5, 6, and 7 shall apply to this equipment. In addition to the requirements of 6.3.2.3, the design margin shall be established such that:

1) the stress at internal rated working pressure shall not exceed $^{2}/_{3}$ of the minimum material yield strength and

2) the valve design shall withstand a test pressure of 1.5 times the internal rated working pressure with the closure mechanism mechanically held open and the product at ambient temperature. The valve mechanism that maintains the normally closed position may be removed for this test to enable the valve to remain open fully without pressure assist.

A single validation grade (V1) as defined herein is applied to TSSVs.

FAT shall conform to the requirements of Annex B with the exception of performing the internal (ID) integrity test to 1.5 times the rated working pressure with ends capped, the entire ID of the valve exposed to the same pressure, no pressure on the piston/actuation chamber, and the product at ambient temperature.

Post-manufacturing servicing of TSSVs shall conform to the requirements of Annex C with the exception of Level 3 service, which shall conform to the requirements of G.6.

G.2 Design Parameters

Tool designs produced in accordance with this specification shall have passed the supplier/manufacturer documented verification and validation procedures at the tool's rated limits for each size, type, and model.

All of the tool's capabilities shall be defined. The following capabilities and ratings shall be validated:

a) maximum temperature,

b) minimum temperature (if rated to less than ambient),

c) internal rated working pressure at maximum rated temperature (burst direction),

d) external rated working pressure at maximum rated temperature (collapse direction),

e) differential across the closure from below at maximum rated temperature,

f) pressure rating of operating chamber at maximum rated temperature (if less than the internal rated working pressure),

g) integrity test pressure (1.5 times working pressure at ambient temperature),

h) pump-through rate (with valve closed),

i) chemical injection rate,

j) rated collapse/external pressure during closure function,

k) ported slick joint collapse rating,

l) valve closure time,

m) cutting capabilities.

The following capabilities shall be validated or verified:

a) tensile rating at 0 psi,

b) tensile rating at rated working pressure and ambient temperature (calculated),

c) tensile rating at rated working pressure and maximum rated temperature (calculated),

d) service rating for H_2S and CO_2.

Additional ratings may include, but are not limited to, shear sub cutting requirements, erosion, or accumulation of particulates.

Successful completion of the validation test and approval by a qualified person shall qualify the design for manufacture of additional tools of the same size, type, and model as the tested design. The supplier/manufacturer shall have documented specifications for all materials, and materials shall comply with these requirements and the requirements of Section 6.

G.3 Design Validation

G.3.1 General

The supplier/manufacturer shall have documented procedures to validate the stated operational performance ratings of these tools. Each tool design, design variation, and material configuration shall be supported by successful testing or verification at the rated limits of the stated capabilities. All validation/verification results and procedures shall be documented to an adequate amount of detail to allow the process to be replicated. All measured parameters shall be recorded on systems calibrated within the range of use. Verifications and validations shall be compiled or referenced into a report of the tool's performance capabilities that is approved by a qualified person other than the qualified person who performed the testing. Tool ratings shall be within the successfully tested/verified parameters. Test facility and evaluation requirements shall conform to 7.5.1, A.1.2, and A.2.

G.3.2 Internal Pressure Integrity Test

The valve shall be validated to an internal (ID) integrity test of 1.5 times the rated working pressure at ambient temperature with ends capped, the entire ID of the valve exposed to the same pressure, and no pressure on the piston/actuation chamber. The test shall be performed with liquid. The pressure test acceptance criteria is a maximum of 1 % change in the applied pressure, with a decreasing rate of change, over a period of 15 minutes after sufficient time has been allowed for stabilization.

G.3.3 Valve Performance Test

The supplier/manufacturer shall have documented procedures with acceptance criteria for the valve design that permits prediction and repeatability of rates, pressures, activation signals, and the other conditions required for closure. Closure mechanisms shall open and close to a prescribed set of parameters that include time to close and acceptance criteria when closed. The closure mechanism shall be validated to contain the rated differential pressure across the closure mechanism at maximum rated temperature for a minimum of 20 open/closure cycles and 250 psi (±5 %) at ambient temperature for a minimum of 5 cycles.

If the minimum rated temperature is less than ambient, the minimum rated temperature shall be validated by applying the rated differential pressure across the closure mechanism (from an initially closed position) at the minimum rated temperature one time, followed by a pressure bleed-down, and confirming that the closure mechanism can be opened.

The closure mechanism shall be validated to open and close with rated external pressure applied at maximum rated temperature.

The external rated working pressure (collapse direction) shall be validated at maximum rated temperature.

The liquid pressure test acceptance criteria is no more than 1 % change in the applied pressure, with a decreasing rate of change, over a period of 15 minutes after sufficient time has been allowed for stabilization.

A separate gas test shall be conducted at the rated pressure and at ambient temperature on either an assembled valve or a subassembly of the closure mechanism. Nitrogen or other inert gas may be used for the gas test.

The gas leak rate acceptance criteria is less than 20 cm^3 of gas at atmospheric pressure over a 15-minute hold period after sufficient time has been allowed for stabilization after applying the rated differential pressure. The leak rate shall not increase during the hold period.

If the closure mechanism is rated to cut wireline/slickline, a cutting test that validates the specific size and grade of wire shall be performed. The pressure required to perform the cut shall be recorded. If a post-cut leakage rate is specified, the rate shall be derived from the average of three cutting test, each of which may be performed with a new closure mechanism.

If the closure mechanism is rated to cut coiled tubing, a cutting test that validates the specific OD, wall thickness, and grade of tubing shall be performed. The pressure required to perform the cut shall be recorded. If a post-cut leakage rate is specified by the supplier/manufacturer, the rate shall be derived from the average of three cutting tests, each of which may be performed with a new closure mechanism.

If the closure mechanism is rated to cut any combination of the above, a cutting test that validates the specific combination shall be performed. The pressure required to perform the cut shall be recorded. If a post-cut leakage rate is specified by the supplier/manufacturer, the rate shall be derived from the average of three cutting tests, each of which may be performed with a new closure mechanism.

Successful completion of any of the above cutting tests shall include verification that the closure mechanism can be functioned to a supplier/manufacturer-defined open position after the cut.

G.3.4 Actuation Chamber Rating

The control line and actuation chamber (typically piston chamber) shall be validated to 1.5 times the maximum rated pressure of the actuation chamber and maximum rated temperature with no internal bore pressure. The test shall be performed with liquid. The liquid pressure test acceptance criteria is a maximum of 1 % change in the applied pressure, with a decreasing rate of change, over a period of 15 minutes after sufficient time has been allowed for stabilization.

G.3.5 Pump-through Opening Pressure

The valve shall be tested in accordance with supplier/manufacturer procedures to establish the pressure below the closure mechanism at which the closure mechanism opens when the pressure above is at the maximum rated pressure.

G.3.6 Pump-through Performance

The valve shall be tested in accordance with supplier/manufacturer procedures to establish the flow rate vs pressure drop across the closure mechanism with the open control line depressurized.

G.3.7 Shear Sub

The shear sub shall conform to API Specification 5CT.

G.4 Ported Slick Joint

The ported slick joint is typically an integral component the TSSV and will therefore be validated with the valve. The purpose of the ported slick joint is to allow for isolation of the BOP from the casing by closure of the pipe rams and routing of control lines through the BOP. The ported slick joint shall allow sealing between a designated portion of its OD and the BOP pipe rams. It shall be designed to withstand the combined loading of the closed pipe rams, internal/external pressure, and applicable external loading conditions. It shall provide longitudinal through-porting (e.g. hydraulic and/or electrical) for actuation of the TSSV, and chemical injection. It shall include a pump-out shoulder to limit axial movement of the valve within the BOP.

If the ported slick joint is not an integral part of the TSSV, it shall be validated to 1.5 times its maximum rated pressure either when assembled to the valve or in a separate test. Integrity of the through-porting shall be validated to 1.5 times the maximum rated pressure. The tests shall be performed with liquid. The liquid pressure test acceptance criteria is a maximum of 1 % change in the applied pressure, with a decreasing rate of change, over a period of 15 minutes after sufficient time has been allowed for stabilization.

G.5 Auxiliary Equipment

Auxiliary equipment such as hydraulic control panel, hydraulic power unit (HPU), hydraulic hoses and fitting, and emergency shutdown (ESD) interfaces are not covered by this specification.

G.6 Level 3 Service (Periodic Evaluation)

This service ensures that the safety, integrity, and the capability of the tool remains as per the design requirements. Level 3 service shall be performed in the event of any of the following:

a) every 40 jobs or 5 years, whichever comes first;

b) following any job in which the tensile load exceeded 95 % of its rating or after jarring;

c) following any job in which the tool was exposed to conditions that exceeded the supplier/manufacturer's recommendation for CO_2, acid, H_2S, or solids.

Level 3 service shall include all Level 1 and Level 2 service and shall include the following in accordance with supplier/manufacturer's documented procedures.

a) Test and verification of mechanical springs.

b) Perform factory acceptance test in accordance with G.1.

c) NDE on load-bearing and pressure-retaining components including threads.

d) Wall thickness measurement of all internal diameter components. Components with wall thickness below the manufacturer's acceptable corrosion/erosion allowance require replacement.

e) Gauging of threaded load-bearing connections.

f) Radiography on welds.

All criteria shall conform to the supplier/manufacturer's documented acceptance requirements, before the tool is returned to service.

G.7 Test Reporting

A final report of the design validations shall be prepared by a qualified person and approved by a qualified person other than the person who prepared the report. The test report becomes a portion of the tool design documentation. The report shall as a minimum include:

a) testing location(s), date, and person performing the testing;

b) the tool's unique identification, such as part number and serial number;

c) procedures used and records required by those procedures;

d) detailed results and discussion of results, including whether or not the test was successful;

e) approval indications such as signatures.

Annex H
(informative)

Applications Overview

H.1 General

This annex provides general information for user/purchasers of downhole well test tools to help familiarize them with the purpose of these tools. Included is a general description of the function of key tools and the tool categories as described in this standard. The rationale for conducting a well test is presented along with a description of the typical information that can be gained from the test.

H.2 Downhole Well Test Tool Descriptions

For the purpose of this specification, well test tools are defined as a collection of tools that are part of a temporary completion, placed into the well to allow and control the flow of hydrocarbons (fluids) from the reservoir. Reservoir characteristics can be interpreted from the data recorded during the well test in combination with measured properties of the hydrocarbon fluids obtained from samples captured during the test. Downhole well test tools include tester valves, circulating valves, well testing packers, safety joints, well testing safety valves, slip joints, jars, work string tester valves, sampler carriers, gauge carriers, drain valves, and other related equipment. Considerations shall be provided to ensure that the tools are fully compatible with each other and that they can be deployed into the well, safely control the well during the test, and be safely retrieved after the test.

H.3 Applications of Downhole Well Test Tools

During a well test, alternatively known as a drill stem test (DST), a BHA consisting of several tools, which typically include tester and circulating valves, pressure recorders, and a packer, is conveyed downhole on a work string in a cased wellbore. This downhole tool string is part of a temporary completion that allows fluids to safely flow from a reservoir into the work string and up to the surface where they are separated into constituent phases and measured and then either exported, stored, or flared.

The purpose of the DST is to obtain valuable knowledge of the reservoir while flowing on a scale commensurate with what will occur during production. The objective of a DST is to create a sufficient disturbance in the reservoir that will cause a substantial movement of reservoir fluid through the formation to take place. By making key measurements during this transient event, such as fluid movement into the wellbore (flow rate) and the resulting near-sandface pressure change (bottomhole pressure), it is possible to match the observed measurements with the solution to the differential equation that describes the flow of fluids through porous media. Therefore, by inversion of the remaining unknown parameters in the flow equation with the measurements made during the well test, key formation parameters may be inferred. These parameters include the permeability-thickness product (kh) and formation damage skin (s). Other parameters that are present in the flow equations, such as fluid and formation properties, are determined from the analysis of other geophysical data and captured samples.

A well test is usually conducted by first flowing the well for a period of time (drawdown period) followed by ideally closing the well downhole and allowing the reservoir pressure to build back up (buildup period). This sequence can be repeated as necessary. If the well is allowed to flow for a sufficient amount of time, contact of the pressure disturbance with the reservoir boundary can be detected from the downhole pressure measurement, which leads to a determination of the reservoir extent, a key assessment of the hydrocarbon reserves in place.

A major value of a DST is that dynamic test results are obtained on a large reservoir scale, and large volumes of uncontaminated fluid samples can be captured. Thus, derived parameters such as permeability represent values that are averaged from deep within the reservoir as opposed to near-wellbore measurements obtained from logging tools.

Downhole well test tools may also be used during operations such as stimulation, production flow back, and perforating.

H.4 Downhole Well Test Tool Types

H.4.1 General

Well test tools are offered in a wide variety of designs and configurations to match the needs of the user/purchaser. Therefore, the requirements of this standard are authored in a general and performance-based manner. Detailed operational capabilities and limitations are included in the supplier/manufacturer's tool documentation.

H.4.2 Circulating Valves

A circulating valve allows a fluid path to be opened between the annulus and the ID of the work string. The circulating valve provides a means to circulate, or reverse, fluids to or from the ID of the work string. Fluids can be pumped from the surface into the work string (circulation) and allowed to enter into the annulus at the position of the circulating valve. Circulation can be used to displace the original fluid in the annulus and work string with another fluid having a different density or characteristics. Alternatively, fluid can be pumped from the surface into the annulus (reversing), causing the annulus fluid to enter into the work string at the position of the circulating valve and displace the existing tubing contents to the surface. Reversing is typically used to flush volatile hydrocarbons from the work string before removing the well test tools after a test.

Circulating valves are designated as being either multi-cycle or single-cycle type. A multi-cycle valve can be opened and closed multiple times, while a single-cycle valve is typically initially closed and it is functioned once to open it. If left open, the circulating valve will drain the work string of fluid while POOH to avoid pulling a wet string.

H.4.3 Tester Valves

The tester valve is typically a ball type valve having only open or closed states (i.e. the tester valve is not used to choke or regulate the flow). Shutting in the flow downhole close to the formation with the use of a tester valve (as opposed to simply using a surface valve to shut in the well) minimizes the effects of wellbore storage and fluid segregation when interpreting the pressure buildup. The tester valve can also isolate an initial cushion fluid from the formation before the well test begins and it stops the formation fluid flow during the buildup portion of the well test.

H.4.4 Well Testing Packers

Well testing packers seal between the OD of the well test BHA and the casing ID to isolate the annulus fluid from the formation and serve as a mechanical anchor to the casing. Common methods of setting a well test packer include applying string weight and/or by the application of hydraulic pressure. Well testing packers are typically run and retrieved with the testing string. A well test can also be performed with a completions type packer.

H.4.5 Safety Joints

A safety joint is a device typically installed above the packer that allows an intentional controlled separation of the string or BHA. In the event a packer or the tubing conveyed perforating (TCP) guns below become stuck, a jar (H.4.6) that is typically placed above the safety joint can be activated in an attempt to free the string. If this is unsuccessful, the safety joint above the packer can be disengaged and all tools above can be retrieved from the hole.

H.4.6 Jars

A jar is routinely run within the DST BHA to assist in freeing the packer should it not release, or in the event of sanding. The jar is typically placed above a safety joint (H.4.5), which is in turn placed just above the packer. Internally, a jar consists of a hammer and anvil that are linked to opposite ends of the tool and that are free to move independently of one another. The hammer and anvil are initially maintained apart by the so-called jar *stroke*.

Elastic energy is initially stored in the work string by applying an overpull at the surface. The resulting tensile force in the jar results in the hammer releasing so that it accelerates and strikes the anvil, creating an impact force to help free the string. Because the potential energy stored in the string is suddenly converted to kinetic energy followed by a sudden impact, the dynamic force delivered is greater than the static overpull. When weight is set back down on the jar, it is reset so that another overpull can be applied and the process repeated.

If sticking is severe (i.e. due to excessive sand production or hole collapse) and multiple blows with the jar are unable to free the string, the safety joint below the jar can be disengaged and all DST tools and gauges above the packer can be pulled out of the hole. A more powerful jar can then be run and more aggressive jarring performed in an attempt to free the packer and any equipment below.

H.4.7 Work String Safety Valves

A work string safety valve placed within the well testing BHA is used to shut in the well should there be a leak in the work string above the safety valve. It can also be used as a backup valve in case of a tester valve failure. When triggered, usually using a rupture disc exposed to annulus pressure, the normally open, single-cycle valve will close. Some safety valve designs allow pump-through capability from above to allow fluid to be bullheaded into the formation. Valve mechanisms are usually of a ball or flapper type. Some safety valves also allow circulating capability when activated.

H.4.8 TSSVs

A TSSV is sometimes deployed in the string (see Annex G). This pump-through type valve may have chemical injection capability, and it is placed nearer to the surface as another means of closing in the well should an emergency occur. Such valves are operated by a hydraulic control line from the surface in a fail-closed manner; positive control line pressure is needed to keep the valve open while any loss of control pressure will result in the valve closing. These valves are typically used on jack-up or land-based operations.

H.4.9 Slip Joints

A slip joint is a telescoping expansion/contraction tool that accommodates changes in string length caused by temperature and pressure changes during the well test. Multiple slip joints can be deployed in a well test string to handle the amount of expansion/contraction predicted by calculations performed prior to the well test.

H.4.10 Sampler Carriers

A sampler carrier is a tubular component designed to hold and convey multiple smaller-diameter sampler tools into the well. Fluid samplers are used to capture a downhole fluid sample during a well test for retrieval at the surface when the test is completed. The individual sampler tools generally range from 25 mm to 44 mm (1 in. to 1.75 in.) in diameter, and multiple tools are typically installed around the circumference of the sample carrier, either on the OD or within the ID of the carrier. While the fluid samplers are outside the scope of this standard, the carrier is an integral part of the testing string that must provide tensile load and differential pressure integrity that is consistent with the other well test tools.

H.4.11 Gauge Carriers

Similar to a sampler carrier, a gauge carrier conveys pressure/temperature recorder(s) downhole. It consists of a tubular component upon which the recorder(s) are mounted. The recorders can typically be ported to measure tubing or annulus pressure. Gauges, also referred to as recorders, continuously measure and store downhole pressure and temperature during a well test. This data is retrieved from the gauge's internal memory when the test string is brought to the surface at the end of the well test. Retrieval of the data during the well test is also possible with wireline intervention and newer wireless telemetry technologies. Downhole gauges and their associated metrology are outside the scope of this standard.

H.4.12 Drain Valve

A drain valve is designed to safely vent any trapped pressure between or within tools before breaking out threaded connections in the string or disassembling a tool. A drain valve may be incorporated into a tool assembly, or it may be a standalone tool.

H.4.13 Work String Tester Valves

These are valves designed to close the work string near or within the BHA to test the work string by the application of surface pressure. The valve allows multiple pressure tests of the work string to be performed when RIH. A variety of designs exist for these valves such as the following.

— Ball valve types that remain closed while RIH until the valve is permanently opened by pressurizing the annulus to rupture a disc. These valves may have to be manually filled, depending on the design.

— Flapper valve types that allow the string to automatically fill from below while RIH. As the string is deployed, fluid lifts the flapper and allows the string to fill. Applying pressure from the surface pushes the flapper down against its seat to allow the production string to be tested. When the test string is at final depth and the tubing tests have been completed, the flapper can be permanently locked open.

Annex I
(informative)

Operational Recommendations

I.1 General

This annex provides recommendations to help ensure that a downhole well test tools can be deployed safely and effectively so that operational objectives are achieved and the string safely recovered. This annex shall be used for guidance only and may not contain all aspects that require consideration.

All information requested in this annex such as calculations, analyses, procedures, and testing results shall be recorded and retained for reference.

I.2 Safety Considerations

Conducting operations in a safe manner shall be the priority when designing, planning, and executing downhole testing operations. A full review of the system shall be conducted and any concerns addressed. The operator and service supplier shall analyze and document the planned operations to understand the potential risks and mitigations in each part of the operational sequence and ensure familiarization of the operational personnel.

I.3 Communication of Job Objectives

The operator shall provide clear objectives for the job to the service provider(s). Refer to 5.3 and 5.4 for a partial list of well and operational parameters that may be considered when planning a job.

I.4 Job Design Considerations to Meet Operational (Job) Objectives

The following considerations are to be applied in the job design process. This is not intended to be a fully inclusive list.

1) Early involvement in design of the well construction details is imperative to ensure that operations can be performed safely and effectively.

2) Consider all load cases in the job design such as tensile forces, anticipated temperature changes, and absolute and differential pressures acting on the downhole well test tools and well system. Absolute and differential pressure exposure is a function of hydrostatic pressure, formation pressure, thermal effects, and applied pump pressures. With different hydrostatic fluid densities in the system, these pressure sources will generate a range of surface and differential pressures that need to be effectively managed.

3) The operator and service provider should communicate as early as possible regarding the expected fluid exposure, well conditions, their impact on well test tool operation, and materials including elastomer compatibility. Any additional material(s) evaluations/tests deemed necessary to ensure tool compatibility with a specific well environment may be performed as agreed upon by the user/purchaser and supplier/manufacturer.

4) If reservoir pressure and fluid composition/densities have not been assessed with sufficient accuracy, then a maximum potential pressure and lowest possible hydrostatic fluid gradient should be defined during the planning phase to provide worst-case conditions for the design.

5) Review of the effectiveness and independence of identified well barrier elements within the downhole testing string are to be performed to protect against string failure and any subsequent impact on the well system. Reviews of failure case scenarios are to be addressed for each phase of the operations, from deployment to safe recovery.

6) The fluid flow paths and drainage arrangements are to be considered in the design of the DST string to ensure reservoir access and to effectively and safely be able to kill the well, especially in the event of tool failures. For example, ball valves in the string may fail closed and restrict the ability to kill the well, the potential for testing string elements to trap hydrocarbons when long tail pipe systems are run. Such cases may introduce additional safety and operational restrictions that are to be addressed in the planning phase.

7) Consideration is to be given for valves within downhole and landing testing strings that may require increased applied pressure to achieve effective pump-through for bull heading operations.

8) Detonation of perforating systems may create pressure shock waves that need to be effectively modelled and considered.

9) Careful review of potential unplanned detonation events shall be considered, especially if there is a need to shear the string or if the guns are dropped inadvertently. Inherently safe detonation systems should be considered. Contingency plans for string retrieval should be in place in the event of a perforating system misfire or low-order detonation.

10) Adequate risk assessment and pressure test management procedures are required to minimize the potential risks. Pressure/volume relationships during pressure tests and the impact of leakage shall be considered, for example, pressure leakage causing the detonation of perforating guns.

11) When solids control devices are used, such as screens used with gravel packing, care must be taken to ensure these devices do not affect the test objectives.

12) The potential to trap pressure and/or hydrocarbons between valves or elements within the DST string after it is brought to surface are to be considered.

13) Give consideration to ensure that adequate set-down weight is available for all operational scenarios, including hydraulic effects on the set-down force.

14) Give consideration to accommodate inflow pressure testing.

15) The effect of any solids content on the operation of downhole tools are also to be considered. Fluid type, chemical composition, and the presence of any solids content on the operation of downhole tools are also to be considered.

16) Preparation and planning for unexpected H_2S or other hazardous well fluids escaping at surface are to be considered.

17) Give consideration to the deployment and retrieval of intervention tools through the DST string.

I.5 Well Kill Considerations

Items to be considered for a proper kill operation to minimize formation damage and maintain control of the well are:

1) formation pressure;

2) fracture pressure;

3) kill method such as bull head kill or reverse kill;

4) pressure safety margin, including valve pump-through, for well kill;

5) kill fluid properties, including tendency for formation lock-up;

6) proper lost control material (LCM) or device (e.g. fluid loss control valve) for the formation that is being tested;

7) equipment operating envelope;

8) handling/disposal of hydrocarbons at surface;

9) swabbing effects;

10) flow monitoring/trip tank level;

11) tail pipe design (flow path at top of tail pipe);

12) tubing space out to allow BOP rams to properly close on string;

13) adequate kill fluid volume and weight;

14) adequate pumping equipment/capacity;

15) maximum pressure limitations that have an adverse effect on downhole well test tools in the string such as inadvertent rupture disc activation;

16) casing/tubing pressure limitations.

I.6 Well Barrier Considerations

In the design of the downhole testing string, it is good practice to have at least two independent pressure barrier envelopes during all stages of the operations.

Any well barrier within the well and downhole test system will need to be physically tested (in the direction of flow, if possible) and verified as part of the programmed activities for the operation.

Well barrier and closure diagrams should be created for each step in the operation.

I.7 Considerations for Contingency Operations/Intervention

I.7.1 General

Planning should be performed to accommodate contingency operations such as, but not limited to:

— coiled tubing,

— electric/slick line,

— stimulation,

— fishing.

Job design and tool string configuration shall consider and, where possible, facilitate the requirements for contingency operations.

I.7.2 Tool/String Parameters

I.7.2.1 Pressure Integrity (Equipment Operational Assurance)

Downhole testing and landing string (or subsea/subsurface) tools can be configured in many different ways. Consideration given to equipment functionality and pressure integrity at all stages in the operations can prevent possible operating errors that can lead to potential delays or failures.

Where applicable, tool charging, setup, and operating pressures need to be calculated before the equipment is mobilized to the location of use. Once on location, the charging and operating pressures shall be verified and may require adjustment due to current wellbore information. Included within the scope of charge pressures are:

- calculate and record tool nitrogen charging/operating pressures, considering ambient and downhole temperature effects;
- verify bottomhole pressure and temperature for calculations;
- verify rupture disc and shear device calculations;
- establish surface temperature for calculations;
- verify fluid properties/densities.

To ensure pressure integrity, all tools and connections shall be pressure tested prior to flowing hydrocarbons.

Downhole testing tools should, where appropriate, be individually function and pressure tested, both in the service center and at the well site, before RIH. These tests should address body, valve integrity, and operational testing where appropriate. Testing the tools individually will enable small leaks to be more effectively discovered due to smaller fluid volumes. Care should be taken to avoid the influence of thermal effects such as solar heating when surface pressure testing, as this may mask potential leaks.

Not all surface tests can adequately prove integrity and functionality of the BHA. During deployment and makeup when performing pressure tests, all opportunities should be taken to confirm functionality of the well test tools. Any such tests shall have clearly defined objectives that may verify correct tool functioning.

Fluid volumes to be pumped for pressure testing and/or tool functioning should be estimated beforehand using expected pressure/volume or displacement relationships to help identify any abnormal conditions and manage potential system anomalies. An example is monitoring of the trip tank with an open annulus for expected level changes. All testing results and relevant observations shall be documented.

I.7.2.2 Tool Compatibility

Job design should take into account items such as, but not limited to:

- operational compatibility among tools and equipment within the downhole testing string;
- interfaces, such as compatible threaded connections, rig handling equipment, and dependency on rig control/pumping systems;
- materials, such as compatibility of seals and other materials with wellbore and reservoir fluids;
- qualification of tools and seals for job duration, time-temperature limits of electronics, and battery autonomy.

I.7.2.3 Stress and Thermal Analyses/Compliance with Rated Tool Envelopes

An analysis accounting for all potential load and thermal conditions shall be performed to verify that the downhole test string and associated elements are within the required operating limits. The results of this analysis shall be used to confirm the downhole testing tools and equipment remain within their operational envelopes for all potential load cases.

I.7.2.4 Casing Pressure Limits

Verification shall be performed to ensure that allowable casing pressures are not exceeded as a result of the application of annulus pressure or changes in annulus fluid. This analysis shall also consider failure cases such as tubing leaks close to the wellhead and kill and/or stimulation pressures required.

I.7.2.5 Selection of Work String Connection Type

Past practice was to use the same pipe to perform a downhole well test as was used to drill the well. As higher pressures were encountered and the need arose for improved gas tight performance, many companies advocate the use of proprietary gas tight connections.

The decision tree in Figure I.1 provides guidance on the use of API threaded connections for well test operations. This process will vary according to company policy and regional requirements, but Figure I.1 illustrates an example of the decision process designed to minimize risk.

Due to the uncertain conditions that might be encountered in well testing, it is recommended that the chosen tubing connections be either an industry-accepted proprietary connection or one tested to the requirements of API Recommended Practice 5C5. Proprietary gas tight connections and material grades suitable for sour service are recommended, especially in exploration operations.

I.7.2.6 Tool End Connections

Tool end connections facilitate the interconnection of the various tools within the BHA. Tool end connections are specified by the supplier/manufacturer and are integral to the tool. Tool end connections must withstand the tool's rated tensile, compression, and bending loads while maintaining pressure integrity.

I.7.2.7 Work String Crossovers

Standalone connectors or crossovers that utilize tubing threads are explicitly covered by either API Specification 5CT or other supplier/manufacturer's standards. When one or both ends of the crossover include a proprietary thread form, it may be designed and manufactured to the requirements of Sections 5, 6, and 7 of this specification. Proprietary thread forms shall conform to the requirements and specifications of the licensed thread provider.

I.7.2.8 Space-out

Positioning downhole testing strings requires careful and accurate planning and verification. This planning includes, but is not limited to, achieving on-depth perforation, managing string contraction/expansion, and accurate positioning at the BOP and stick-up at surface.

On deep water tests, it is recommended that a dummy run be performed to establish the exact hangoff position of the string in relation to the BOP and/or to facilitate correlation of perforating guns on-depth. On floating vessels, stick-up is subjected to tidal and wave effects (heave), and this distance should be sufficient so as to allow the safe movement of the rig relative to the test string without risking a collision of the master valve against the rotary table and to prevent damage to the flexible hoses/connections.

I.7.3 Well Considerations (Operational Considerations)

I.7.3.1 Heating Effects

Temperature limitations within the downhole testing tool string, and where appropriate the landing string, shall be considered during the design phase. For example, heating of a closed annulus can result in increased pressure, which may cause inadvertent tool operation. Alternatively, when multiple annuli exist, heating during production can cause increased pressure in intermediate casing strings, which could result in casing collapse. Therefore, fluid expansion factors need to be considered during job planning, and annulus pressures should be monitored during operations. During production, temperature of BOP elastomeric sealing elements and surface equipment can approach their rated operating limits. Heating effects can sometimes be managed by controlling flow rates.

Mud and brine systems can behave differently from heating due to their very different thermal properties. Consideration should be given to mud stability over long periods of time.

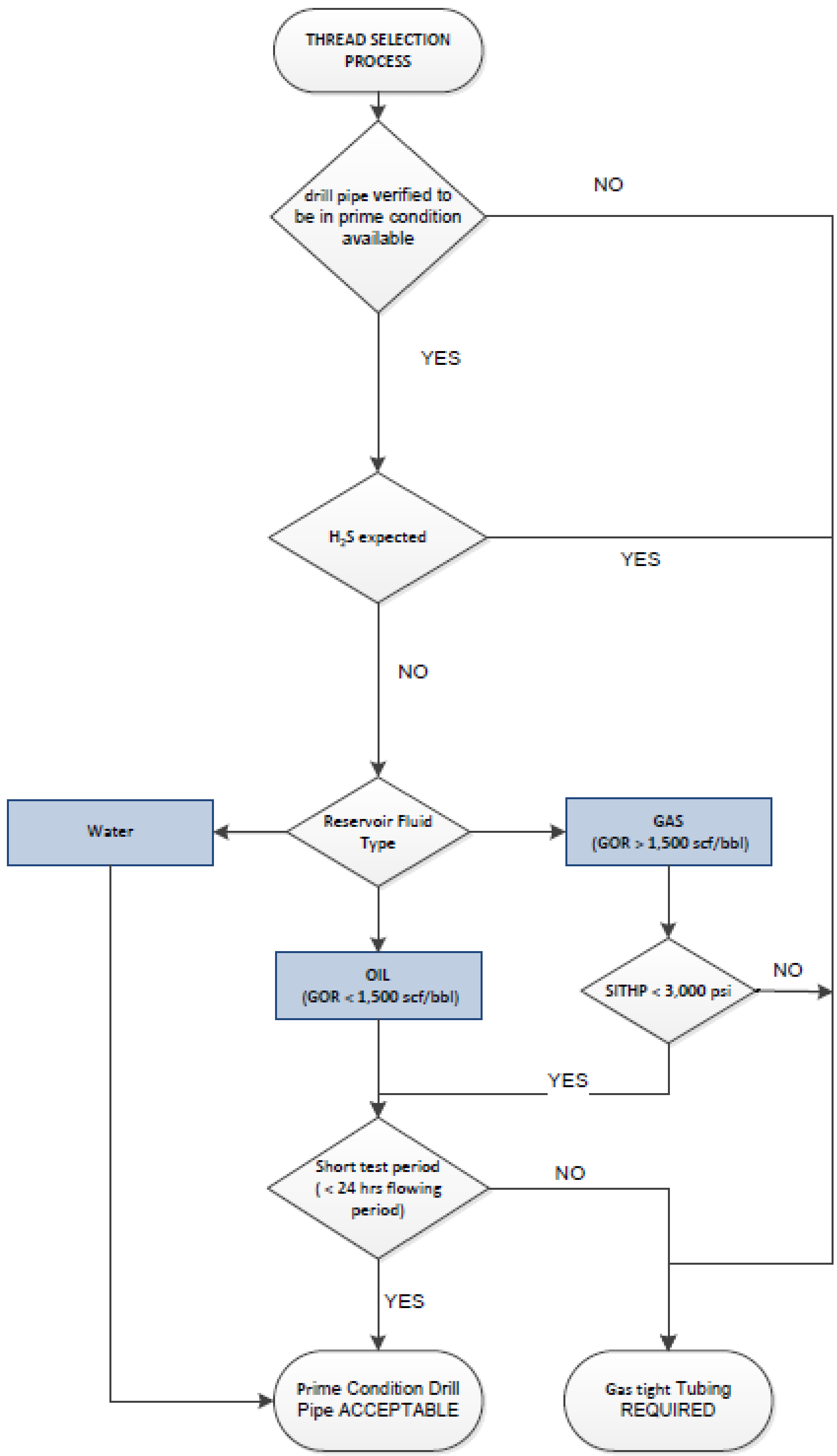


Figure I.1—Example of a Decision Tree for Selection of Work String Connection Type

I.7.3.2 Annulus Pressure Operations

Most downhole testing tools are controlled by the application of annular pressure. Annular pressures are most often managed using the rig pumps and standpipe manifold; however, there are some cases where greater pressure control is needed, in which case the cement pump system may be recommended.

Verification shall be performed to ensure that allowable casing pressures are not exceeded as a result of the application of annulus pressure or changes in annulus fluid. This analysis shall also consider the potential failure cases such as tubing leaks close to the wellhead, kill, and/or stimulation pressures.

Prior to the actual well test operation, casing integrity shall be verified via both positive and negative pressure testing procedures, considering the maximum expected overbalance and underbalance that the casing may be exposed to. Failure to comply with the testing criteria requires corrective operations before testing the well.

Before performing integrity tests, the expected volumes needed to achieve the desired pressure changes should be calculated. Procedures should be available to address any unexpected variations. During these operations, monitoring of all potential systems that could be influenced by the operation should be conducted. The use of near real-time downhole pressure monitoring systems for verification of annular and string pressures can be beneficial for confirmation of tool operations and diagnostics.

The service specialist is responsible for advising the driller of the annular pressures required for proper tool function during well testing operations. Detailed emergency procedures shall be established to address fault conditions.

During flow periods, annulus pressure should be recorded along with the volume of fluid recovered during bleed-off operations to assess fluid expansion trends and confirm pressure integrity. Monitoring and recording of annular pressure through the well testing data acquisition system and mud logging systems can be carried out and the relevant alarms established.

Pressure transmissibility should be considered when heavy mud fluid systems are utilized, potentially resulting in applied pressure not reaching the downhole well test tools.

During buildup periods, thermal cooling and fluid contraction will result in loss of hydrostatic head in the annulus as the liquid level falls. The annulus fluid level should be closely monitored and maintained to ensure well integrity.

I.7.3.3 Valve Status Diagram

It is recommended to have valve status diagrams present on the rig floor so valve statuses will be known to all. Figure I.2 is an example of a valve status diagram (for a floating vessel).

I.8 Additional Considerations

I.8.1 String Deployment with Underbalanced Cushion Fluids

A simple way of introducing underbalanced cushion fluids into the string without the need for activating circulating valves is running the downhole testing strings using the top-fill method. The top-fill method may utilize either a single shot isolation valve, or the downhole tester valve, and the method provides a simple way to introduce a lighter cushion into the tubing. Using this technique creates an additional risk associated with unbalanced hydrostatic pressures between tubing and annulus and the potential for uncontrolled u-tube flow should the isolating valve in the string prematurely activate.

Other methods of string deployment with an underbalanced cushion may include using the circulating valve to place the cushion, using various types of auto fill valves, or nitrogen displacement.

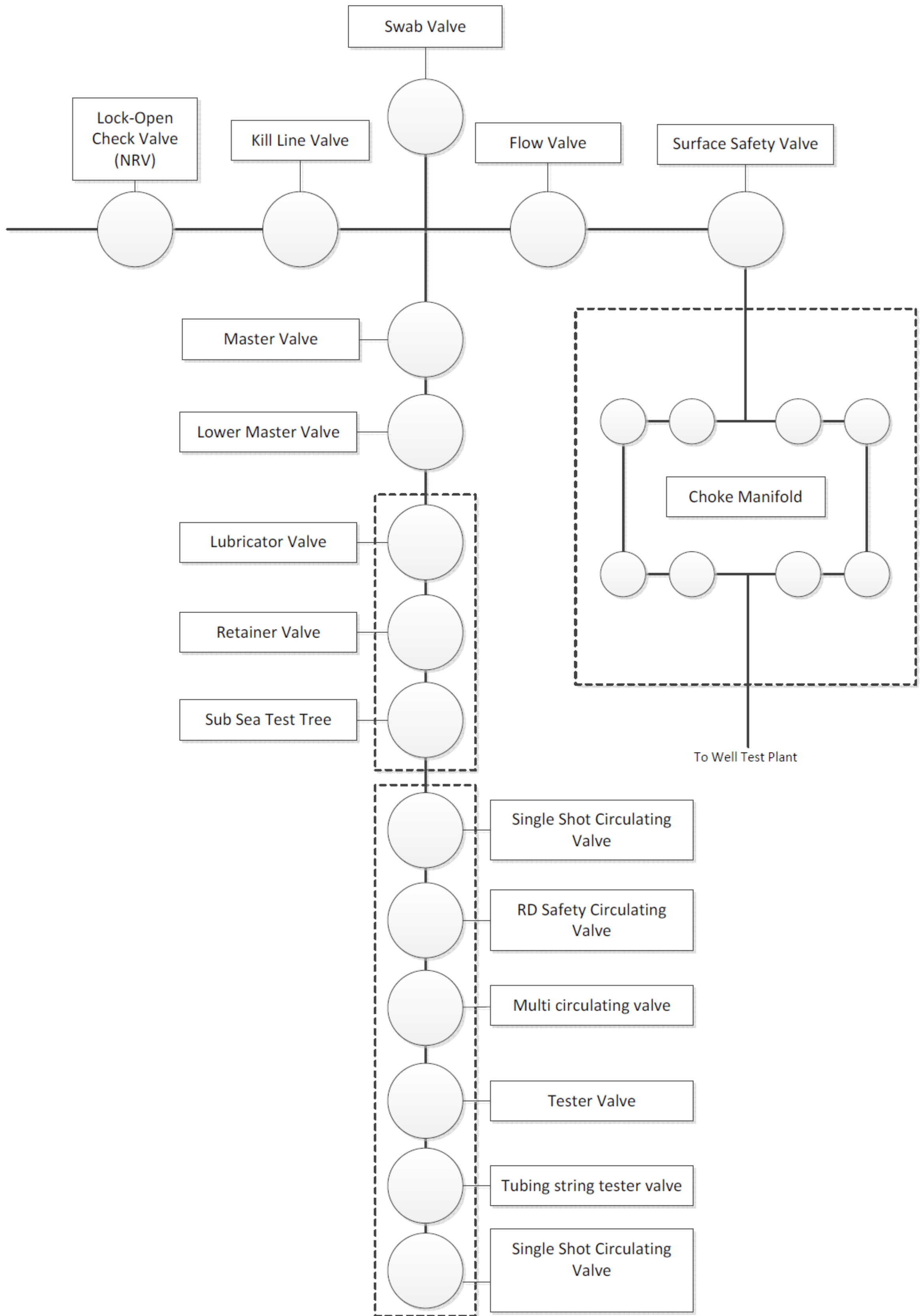


Figure I.2—Example Valve Status Diagram

I.8.2 High Pressure, High Temperature Well Considerations

Downhole testing strings for high pressure, high temperature (HPHT) wells may require tools such as additional downhole valves to serve as extra safeguards. For example, when testing with an underbalanced fluid in the annulus, the additional safety valve can automatically isolate the formation in the event of tubing leak into the annulus.

The following is recommended in HPHT wells.

1) If the well is tested in an underbalance situation, it is recommended to add extra safety to the tool string by including an extra safety and circulating valve. At predetermined pressure, the tubing valve can be closed, isolating the tubing from the reservoir. Circulating ports can be sequentially opened at a point above the safety valve, providing communication between tubing and annulus and enabling reverse circulation of kill weight fluids to secure the well.

2) On land or offshore jack-up wells, it is strongly recommended to use a TSSV with pump-through capability (Annex G), preferably with chemical injection capability installed within or below the BOP, to be able to isolate the tubing from the rig floor.

3) Consideration shall be given to the choice of annulus fluids and their compatibility with the reservoir and influence on the operation of downhole tools.

I.8.3 Gun Activation Timing Considerations

TCP firing systems often utilize delay mechanisms that allow some level of flexibility on the delay timing. A standard pressure-activated TCP firing system time delay may be several minutes. This relatively short time period may not provide sufficient time to resolve potential operational issues while bleeding off to a required underbalance. Under such circumstances there is a strong chance that perforation will occur overbalanced. The general recommendation is to use an appropriate firing delay to permit adequate time to handle operational requirements.

I.8.4 Wellsite Confirmation of Well Parameters

Exploration and appraisal wells may not always have clear indications of the formation fluid type. Downhole test string designs need to consider the possibility of encountering H_2S or CO_2 concentrations. Where possible, it is recommended to use existing static data such as that from wireline formation test tools to make an initial assessment of the reservoir fluid composition. If the presence of H_2S or CO_2 in the fluid is expected, the string and downhole testing tools must be properly designed and configured for that environment. During the clean-up period, analysis of the produced gas using both a multi-gas portable analyzer and stain tube systems is recommended.

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