Downhole Perforating Tools

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Downhole Perforating Tools

1 Scope

This specification provides requirements and guidelines for the design and use of downhole perforating tools and related equipment, for use in the petroleum and natural gas industry.

It also specifies the requirements for reporting and validating operational ratings of downhole perforating tools that are not addressed by any current standards or specifications.

It provides well-defined operational ratings for functionality of downhole perforating tools as provided by the supplier/manufacturer; and defines levels of quality control (QC) for downhole perforating tools including validation requirements, acceptance testing, performance ratings, and service center requirements.

This specification does not include mechanical, abrasive, and water jet.

2 Normative References

The following referenced documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

API Specification 5C3, 7th Edition, *Calculating Performance Properties of Pipe Used as Casing or Tubing*

API Specification 5CT, 10th Edition, *Specification for Casing and Tubing*

API Recommended Practice 19B, 3rd Edition, *Recommended Practices for Evaluation of Perforators*

API Recommended Practice 67, *Recommended Practice for Oilfield Explosives Safety*

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

ASTM A36/A36M, *Standard Specification for Carbon Structural Steel*

ASTM A370, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*

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

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

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

ASTM E45, *Standard Test Methods for Determining the Inclusion Content of Steel*

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

ASTM E112, *Standard Test Methods for Determining Average Grain Size*

ASTM E164, *Standard Practice for Contact Ultrasonic Testing of Weldments*

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

ASTM E273, *Standard Practice for Ultrasonic Testing of the Weld Zone of Welded Pipe and Tubing*

ASTM E309, *Standard Practice for Eddy Current Examination of Steel Tubular Products Using Magnetic Saturation*

ASTM E570, *Standard Practice for Flux Leakage Examination of Ferromagnetic Steel Tubular Products*

ASTM E587, *Standard Practice for Ultrasonic Angle-Beam Contact Testing*

ASTM E709, *Standard Guide for Magnetic Particle Testing*

ASTM E2033, *Standard Practice for Radiographic Examination Using Computed Radiography (Photostimulable Luminescence Method)*

ASTM E2698, *Standard Practice or Radiographic Examination Using Digital Detector*

Arrays ASTM E3024/E3024M, *Standard Practice for Magnetic Particle Testing for*

General Industry ISO 9712, *Non-destructive Testing – Qualification and Certification of*

NDT Personnel

NACE MR0175/ISO 15156, *Petroleum and Natural Gas Industries—Materials for Use in H_2S-containing Environments in Oil and Gas Production*

3. Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

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

3.1.1
assembly
Product composed of more than one component.

3.1.2
carrier
A component of a perforating gun assembly that houses the internal components.

Examples: shaped charges, detonation cord, charge holders, and other items.

NOTE: The carrier may have different configurations on the outside diameter. Typical OD configurations may be scalloped, grooved, or slickwall. Scalloped and grooved features usually are designed to align with the trajectory of the perforating jets.

3.1.3
cut condition
The percentage of the remaining cross-sectional area that is capable of supporting a tensile load or force applied to the target.

3.1.4
differential pressure
Difference between internal and external pressure or the difference in pressure across a closure mechanism or seal.

3.1.5
downhole perforating tools
Assemblies, components, and parts that are used to convey, initiate, detonate, actuate, retain, anchor, and release the perforating tool string.

3.1.6
energetics
Materials contained in downhole perforating tools that may not be classified as explosives but that provide a release of energy.

3.1.7
firing head
Device used to initiate the detonation as related to downhole operations.

3.1.8
model
Equipment with unique components and operating characteristics, which differentiate it from other equipment of the same type with different configurations.

3.1.9
operating manual
Publication issued by the manufacturer, which contains detailed data and instructions related to the design, storage,

installation, operation, and maintenance of equipment.

3.1.10
operational pressure
The maximum external pressure under which equipment will perform during normal operating conditions.

3.1.11
perforating gun
Device used to perforate oil and gas wells using shaped explosive charges.

3.1.12
pipe recovery cutter
Device that intentionally cuts or severs oilfield tubulars and drill pipe using expelled material.

Examples: These include explosive (jet), thermite, propellant, and chemical jet.

3.1.13
product family
A group of assemblies in which the same design configuration principles apply to materials, geometry, and functionality.

3.1.14
qualified person
An individual or individuals with competencies gained through training and experience as measured against established requirements. (standards or tests).

3.1.15
service center
A location where equipment is inspected, repaired, and tested to maintain supplier/manufacturer specifications. A service center is a physical location apart from the well site.

3.1.16
shot density
The number of shots per unit of length.

3.1.17
size
Relevant dimensional characteristics of the equipment as defined by the supplier/manufacturer.

NOTE: Perforating gun sizes are defined by nominal OD dimension of carrier tubing.

3.1.18
spacer
Device used to stagger the spacing of perforating guns within a tool string.

3.1.19
survival pressure
The maximum allowable pressure exposed to a tool during conveyance.

3.1.20
test pressure
Pressure at which the equipment is tested based upon all relevant design criteria.

3.1.21
type
Equipment with specific functionality that can be differentiated by model and unique characteristics, which differentiate it from other functionally similar equipment.

3.1.22
Type 1 component or weld
A component or weld that isolates pressure and/or may be loaded in tension as the result of axial loads on the perforating tool during run-in, activation, detonation event, in situ, or retrieval.

3.1.23
Type 2 component or weld
A component or weld that does not meet the criteria of a Type 1 component.

3.2 Acronyms and Abbreviations

COC	certificate of compliance
ID	inside diameter
MTR	material test report
NDE	nondestructive examination
NDT	nondestructive testing
OD	outside diameter
PSL	product specification level
QC	quality control
QL	quality level
UNS	unified numbering system

4. Functional Specification

4.1 General

The user/purchaser shall prepare a functional specification to order products that conform to this specification and specify the following requirements and operating conditions, as applicable, and/or identify the supplier/manufacturer's specific product. These requirements and operating conditions may be conveyed by means of a dimensional drawing, datasheet, or other suitable documentation.

4.2 Product Type Description

The user/purchaser should specify the following product type(s):

— a) perforating gun;

— b) pipe recovery cutter;

— c) conveyance connectors;

— d) booster;

— e) firing head;

— f) gun anchor/hanger;

— g) release tool;

— h) setting tool.

4.3 Well Parameters

The user/purchaser should specify, as applicable, the following well parameters:

— a) dimensions, material, and grade of the casing and tubing;

— b) end connections;

— c) well angle from the vertical;

— d) deviations and restrictions product must pass through;

— e) configuration of tubing (single or multiple strings);

— f) location and orientation of other lines (electrical, hydraulic, fiber optic);

— g) relationship of the perforating tool with other well devices, tubing, casing by means of a well schematic drawing, if applicable;

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

— i) maximum pressure;

— j) maximum temperature;

— k) maximum expected time at temperature and pressure;

— l) wellbore fluids and/or gases;

— m) known conditions of well structure or equipment such as scaling, paraffins, NORM, corrosion;

— n) depth of zones and correlation process (short joints, radioactive markers, etc.);

— o) any other relevant well parameter(s).

4.4 Operational Parameters

The user/purchaser should specify the following operational parameters:

— a) installation method, including conveyance method;

— b) activation method and number of times activated or manipulated;

— c) equipment operating depth (setting, activating, or firing);

— d) retrieving method;

— e) representative well schematic;

— f) well pumping operations including fluids and solids composition, flow rates, and exposure time;

— g) anticipated loading conditions, including combined loading (pressure, tension/compression) and torque, applied to the perforating tool prior to and during activation, during use, and during retrieving;

— h) expected activation temperature and anticipated temperature profile, exposure time during well operations, and completion processes;

— i) size, type, and configuration of devices to be run through or over the perforating tools;

— j) any other relevant operational parameter(s).

4.5 Environmental Compatibility

4.5.1 General

If the user/purchaser has access to the corrosion property data of the operating environment based on historical data and/or research, they should state to the supplier/manufacturer which material(s) has the ability to perform as required within the corrosion environment. Otherwise, material compatibility should be specified according to section 4.5.2.

4.5.2 Well Environment

The user/purchaser should identify the density, chemical/physical composition, and the condition of the fluid and/or its components, including solid, liquid, and/or gas, to which the perforating tool is exposed during its expected life cycle.

The user/purchaser should identify when compliance with NACE MR0175/ISO 15156 (all parts) for sour service is required.

4.5.3 Storage and Transportation Environment

The user/purchaser should reference the storage and transportation requirements as defined by the supplier/manufacturer. If deviations are requested by the user/purchaser, the deviations should be specified when requesting services.

4.6 Compatibility with Related Well Equipment

The user/purchaser should identify the following:

— a) top and bottom tubular connection(s), the material (including any supplemental and/or annex requirements required in an internationally recognized standard such as API 5CT or API 5CRA), and dimensions;

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

— c) configuration of other products and conduits to be used in connection with this product, including material, size, and type;

— d) retrieving requirements such as fishing neck, internal or external profile, or other geometry.

4.7 Design Validation

The user/purchaser should specify the required design validation grade. This specification provides five design validation grades (V4 to V0), as defined in 5.5 and the annexes. The selected design validation grade applies to all validation testing per applicable annexes.

4.8 Quality Control

The user/purchaser should specify the required quality level (QL). This specification provides three quality levels (QL3, QL2, and QL1) of QC, as defined in 6.4.1.

5. Technical Specification

5.1 General

The supplier/manufacturer shall prepare a technical specification that conforms to the requirements defined in the functional specification. If the technical specification does not fully meet the functional requirements, the supplier/manufacturer shall identify the differences to the user/purchaser. The supplier/manufacturer shall also provide to the user/purchaser the product datasheet defined in 6.2.3.

5.2 Technical Characteristics

The product shall perform in accordance with the functional specification during installation, activation, operation, and retrieval. The product shall not compromise well intervention operations, unless that is the intended functional result.

5.3 Design Requirements

5.3.1 General

Products conforming to this specification shall be manufactured to drawings and specifications that are substantially the same as those of the same size, type, and model of product that was validated. See applicable scaling limitations related to validation in 5.7.

5.3.2 Design Documentation

Design of products manufactured to this specification shall include documentation of those designs. This documentation shall include design requirements, assumptions, analysis methods, comparison with previous designs or operating history of similar products, calculations, manufacturing drawings and specifications, design reviews, and/or physical testing results (such as design validation testing).

5.3.3 Materials

5.3.3.1 General

Materials (both metallic and nonmetallic) shall be stated by the supplier/manufacturer and shall be suitable for the environment specified in the functional specification. The manufacturer shall have documented specifications for all materials, and all materials used shall comply with the manufacturer's documented specifications.

Material substitutions require approval by a qualified person from the supplier/manufacturer and the supporting documentation incorporated into the manufacturing records.

5.3.3.2 Metals

5.3.3.2.1 General

Steel tubulars for perforating gun carriers shall be specified as per Annex A. All other metals shall be specified as per 5.3.3.2.2 and 5.3.3.2.3.

5.3.3.2.2 Specifications

The manufacturer's specifications shall define:

a) unified numbering system (UNS) number or chemical-composition limits;

b) heat treatment conditions;

c) mechanical property limits:

   1) tensile strength;

   2) yield strength;

   3) elongation;

   4) hardness.

5.3.3.2.3 Mechanical Property Verification

When required by the user/purchaser, the mechanical properties for metal components shall be verified by tests conducted on a material sample produced from the same heat of material. The material sample shall experience the same heat treatment process (or processes) as the finished component it qualifies.

5.3.4 Performance Rating

The supplier/manufacturer shall state the performance ratings for the following: pressure, temperature, axial loads, disconnect, (re)connect, and tubing movement, as applicable for the products.

5.4 Design Verification

5.4.1 General

Design verification shall be performed to ensure that each perforating tool design meets the supplier/manufacturer's technical specifications, including:

— a) all conveyance methods;

— b) operational processes;

— c) removal methods and tools;

— d) contingencies; and

— e) all rated functionalities.

Design verification includes activities such as design reviews, design calculations, testing, comparison with similar designs, and historical records of defined operating conditions. Verification results shall be approved by a qualified person, and records of the results shall become a portion of the design documentation.

5.4.2 Design Assumptions

The supplier/manufacturer shall apply a design margin to each component and/or assembly using a documented methodology and practice. The documented design margins shall be used in the creation of component or assembly capabilities and/or ratings.

5.4.3 Design Calculations

The supplier/manufacturer shall apply and document an industry-acceptable calculation methodology.

5.5 Design Validation

5.5.1 General

This specification specifies five grades of design validation. V4 is the lowest grade established. The performance level is defined by the supplier/manufacturer for perforating tools that do not meet the criteria found in grade V3. Each product design shall be validated to the grade selected by the user/purchaser. Products shall be supplied to at least the design validation grade specified. The validation grades are summarized in Table 1, and validation grade specifics are defined in applicable annexes. The supplier/manufacturer shall meet the validation test requirements of Table 1 to the selected validation grade.

Products validated to higher grades of design validation may be considered validated for lower grades of design validation in accordance with Table 2.

5.5.2 Requirements of Design Validation

5.5.2.1 The supplier/manufacturer shall document the validation test procedure, acceptance criteria, and results and shall have on file material specifications, material certifications, and drawings that show all the applicable dimensions and tolerances of parts contained in the validation-tested product.

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

5.5.2.3 Validation test results and dimensional test results shall be approved by a qualified person other than the person performing them, and records of the results shall become a portion of the design documentation.

5.5.2.4 Evaluation and justification for any dimensions that changed from pretest inspection shall be documented as part of the acceptance and become part of the design file.

5.5.2.5 Components and assemblies not specified in this section shall be validated by a method defined and documented by the supplier/manufacturer.

5.5.2.1 Tandems and Connecting Hardware

Tandems and connecting hardware shall be validated by one of the following:

a) Design calculation per 5.4.3 and a pressure test shall be performed for V3 to V0 to the tool's pressure rating at ambient temperature. Validation by design calculation only is limited to V4.

b) The design calculation for validation grades V3 to V0 shall be per the following.

  1) ACME and Stub-ACME: ASME B1.5 and/or the Machinery's Handbook latest edition.

  2) Straight VEE: Machinery's Handbook latest edition.

  3) API threads shall follow the appropriate API specification for the specific thread type.

     Example: tubing and casing threads per API 5B

  4) Any other thread type (including proprietary) shall have a defined methodology by the manufacturer.

5.5.2.2 Pipe Recovery Cutters

Pipe recovery cutters shall be validated in accordance with Table 1a to the requirements of Annex B for validation levels V3 to V0.

5.5.2.3 Perforating Gun Systems

Perforating gun systems shall be validated in accordance with Table 1a to the requirements of Annex C for validation levels V3 to V0.

5.5.2.4 Firing Head Systems

Firing Head systems shall be validated in accordance with Table 1b to the requirements of Annex D for validation levels V3 to V0.

5.5.3 Validation Test Requirements

5.5.3.1 General

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

When testing to a specific annex, tests shall be conducted in series without redressing critical components, such as seals. Redress or adjustment of non-validated components, such as fixtures or connections, is accepted.

Table 1a—Summary of Design Validation Grades for Perforating Guns & Cutters

Validation Grade	Validation Test Requirements for Perforating Guns Annex C				Validation Test Requirements for Cutter Annex B
	Static Collapse Pressure	**Dynamic Survivability**	**Drop Impact**	**Perforating Gun Threaded Connections**	
V4	Supplier/ manufacturer-defined	Supplier/ manufacturer-defined	Supplier/ manufacturer-defined	Supplier/ manufacturer-defined	Supplier/ manufacturer-defined
V3	Single collapse test	Single test with nominally loaded charges	Single drop test	Calculation by defined method including safety factor	Collapse survival at ambient temperature, functional test at ambient pressure and temperature
V2	Single collapse test	Single test with overloaded charges defined by supplier/ manufacturer	Single drop test	Calculation by defined method including safety factor and temperature rating	Functional test at operational pressure, ambient temperature
V1	Single collapse test	Single test with 3 % min. overloaded charges	Single drop test	Calculation by defined method including safety factor and temperature rating	Functional test at operational pressure with witness plate
V0	Single collapse test	Single test with 5 % min. overloaded charges	Single drop test	Calculation by defined method including safety factor and temperature rating	Functional test at operational pressure and temperature with witness plate

Table 1b—Validation Grades for Firing Heads

Validation Grade	Validation Test Requirements for Firing Heads Annex D	
	Pressure Ratings	**Actuation Load**
V4	Supplier/ manufacturer- defined	Supplier/ manufacturer- defined
V3	Calculated by Von Mises with LMC, & SF=1.2	Calculated by industry defined methodology
V2	Test at pressure with SF=1.2 applied	Function Test at load
V1	Test at pressure and temperature	Function test at load & temperature
V0	Test at 1.1 times pressure & 1.05 times temperature	Function test at load & 1.05 times temperature

Table 2—Design Validation Grade Hierarchy

Design Validation Grade	Grades Covered
V0	V0, V1, V2, V3, V4
V1	V1, V2, V3, V4
V2	V2, V3, V4
V3	V3, V4
V4	V4

5.5.3.2 Validation Requirements for Other Tools

Functionalities not addressed in Table 1 shall be validated by testing to their rated limits or fully evaluated to documented procedures including acceptance criteria and be approved by a qualified person(s). The procedures and results shall be incorporated into the design file.

5.6 Design Changes

5.6.1 All design changes shall be documented and reviewed against the design verification and design validation to determine if the change is a substantive design change. A design that undergoes a substantive change becomes a new design requiring design verification as specified in 5.4 and design validation as specified in 5.5. Design changes identified as non-substantive shall include documented justification.

5.6.2 The supplier/manufacturer shall consider the following:

— a) stress levels of the modified or changed components;

— b) material changes;

— c) functional changes.

5.6.3 Changes to a component or series of components may be identified as a substantive change and require design validation. This may be done by testing only the component or series of components, rather than the entire assembly. The test shall adequately simulate the loading conditions that would be present if the entire assembly were tested. The supplier/manufacturer shall document the detailed test results and analysis that demonstrate that the component test adequately simulates the required loading conditions. Evaluation results shall be approved by a qualified person other than the person performing them, and records of the results shall become a portion of the design documentation.

5.7 Design Validation Scaling

5.7.1 General

4.7.1.1 Scaling may be used to validate variations of a validated product in the same product family and be of the same design factors, type, and model. Only products that have been previously validated to grades V0 through V4 (see 5.5) and in accordance with the requirements and limitations of 5.7.2 can be scaled. The product validated by scaling shall carry the same validation grade as the validated product.

4.7.1.2 A product family is a group of assemblies where the same design configuration principles apply to materials,
geometry, and functionality.

4.7.1.3 The supplier/manufacturer shall establish the maximum stress within the previously validated designed components and in the same components of the scaled design. The mode of stress and same method of calculation(s)/verification(s) shall be applied to the identified components of the base design and the scaled design. For the component with the highest design stress factor, the scaled design's stress factors shall not exceed the stress factor of the same component of the validated design. Stress factor is the ratio of stress to the minimum yield strength of the material.

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

5.7.2 Limitations of Scaling

5.7.2.1 Perforating Guns

4.7.2.1.1The limitations for scaling perforating guns are:

a) OD: Changes in OD that affect the minimum or maximum material conditions would require validation.

b) Wall Thickness: Reduction of minimal wall thickness would require validation.

c) Material Grade: Reduction in mechanical properties requires validation.

d) Scallop Thickness: Reduction in the scallop thickness requires validation.

e) Shot Density: Increasing shot density shall require validation.

f) Shot Phasing: Shot phasing can have significant effect on the survivability of a gun system. The supplier/ manufacturer shall provide a methodology for determining acceptable scaling of family products with regards to changes in shot density.

g) Explosive Load (or Charge): Increase in explosive or energetic material output in the gun system then requires validation.

h) Length of Gun: The supplier/manufacturer shall provide a methodology for determining acceptable scaling for any changes in the length of gun that does not affect the shot density and or the explosive load.

4.7.2.1.2 The charge family, type, and design should be considered in scaling evaluation. The drop test validation is only required when there is a change in the internal system components. This would exclude changes in explosive materials such as HMX vs RDX charges or other explosive materials.

5.7.2.2 Firing Heads

Limitation of scaling limitations for scaling firing heads are any change that would reduce the ratings (pressure, temperature, tensile, torque).

Material changes to load bearing components are changes that would result in the increase/decrease in actuation limits including:

a) Shear values
b) Applied load/pressure
c) Displacement (piston)
d) Flow rate / volume
e) Differential pressures

Changes in the energetic materials (type & amount). Changes should consider the following affects:
a) Increase in energy
b) Increase output, pressure, shock load
c) Decrease in energy
d) Reduction in transfer energy
e) Reliability
f) Temperature

5.7.2.3 Accessories

Tools that incorporate energetic materials shall be validated per the supplier/manufacturer-defined methodology. An increase in energy density load in the tool shall require new validation.

6. Supplier/Manufacturer Requirements

6.1 General

This section contains the detailed requirements to verify that each product manufactured meets the requirements of the functional and technical specifications. These include requirements for documentation and data control, product identification, QC, functional testing, repair, redress, shipping, and storage.

6.2 Documentation and Data Control

6.2.1 General

5.2.1.1The supplier/manufacturer shall establish and maintain documented procedures to control all documents and data that relate to the requirements of this specification. These documents and data shall be maintained to demonstrate conformance to specified requirements. All documents and data shall be legible and shall be stored and retained in such a way that they are readily retrievable in facilities that provide a suitable environment to prevent damage, deterioration, or loss. Documents and data may be in any form of type of media, such as hard copy or electronic media. All documents and data that relate to the requirements of this specification shall be available and auditable by the user/purchaser.

5.2.1.2 All intellectual property and confidential information shall be managed by agreement between manufacturer/ supplier and user/purchaser.

5.2.1.3 All documentation and data associated with design verification (see 5.4), design validation (see 5.5), design change justification (see 5.6), and the design file shall be maintained for 10 years after date of last manufacture.

5.2.1.4 Quality documentation includes all documents, records, and data necessary to demonstrate conformance to 6.4.1 through 6.4.8. Quality documentation shall be retained by the supplier/manufacturer for a minimum of five years from date of manufacture or repair. These shall be available and auditable by the user/purchaser.

6.2.2 Operating Manual

An operating manual shall be available for all assemblies supplied in accordance with this specification. Operating manuals shall contain the following information, where applicable:

— a) manual reference number;

— b) parts list;

— c) operational procedures and related tools;

— d) preinstallation inspection procedures;

— e) representative drawing showing major dimensions (ODs, IDs, and lengths);

— f) troubleshooting;

— g) installation instructions;

— h) field testing instructions;

— i) requirements for handling, shipment, and storage;

— j) requirements for redress and repair, including items such as procedures, tools, and spare parts.

6.2.3 Product Datasheet

Product datasheets shall be available to the user/purchaser, as required in 5.1, and shall contain the following information where applicable:

— a) name of supplier/manufacturer;

— b) product size, type, and model;

— c) manufacturer product number;

— d) manufacturer product name;

— e) metallic materials;

— f) nonmetallic materials;

— g) minimum ID;

— h) OD;

— i) overall length;

— j) temperature range;

— k) temperature cycle range;

— l) disconnect ratings;

— m) disconnect unloading pressure;

— n) number of disconnects;

— o) disconnect load;

— p) (re)connect ratings;

— q) (re)connect temperature;

— r) number of (re)connects;

— s) shear device min and max values;

— t) internal and external differential pressure ratings;

— u) tensile load ratings;

— v) top connection(s);

— w) bottom connection(s);

— x) casing or tubing range, size, and mass and/or minimum and maximum casing or tubing IDs;

— y) maximum conveyance OD, inclusive of running/repositioning equipment;

— z) maximum retrieval OD, inclusive of post detonation or equipment;

— aa)conveyance and retrieval, tools;

— ab) any other rated functionalities (5.5.3.2);

— ac) QL;

— ad) design validation grade;

— ae) operating manual reference number.

6.3 Product Identification

Each product furnished to this specification shall be permanently identified according to the supplier/manufacturer's procedures. The supplier/manufacturer's procedures shall define the type, method of application, and location of the identifications. The identifier shall provide traceability for the following information:

— a) supplier/manufacturer identification;

— b) supplier/manufacturer product number;

— c) the date of manufacture;

— d) QL;

— e) design validation grade;

— f) for QL1, a unique serial and traceability number.

6.4 Quality Requirements

6.4.1 General

6.4.1.1 This specification defines three QLs: QL1, QL2, and QL3 as defined in Table 3. Products shall be supplied to at least the QL specified. When no QL is selected by the user/purchaser, a minimum of QL3 shall be supplied.

6.4.1.2 The supplier/manufacturer shall establish and implement specifications for all quality processes used on products conforming to this specification. These specifications shall include the procedures, inspection methods, and acceptance criteria and shall be approved by a qualified person(s).

Table 3—Quality Level Definitions

Item	Quality Level		
	QL3	**QL2**	**QL1**
Metallic material	Supplier/Manufacturer-defined	certificate of compliance (COC) or material test report (MTR)	— MTR for Type 1 components — COC or MTR for Type 2 components
Nonmetallic material	Supplier/Manufacturer-defined	COC or MTR	COC or MTR
Castings	Supplier/Manufacturer-defined	COC	— MTR for Type 1 components — COC or MTR for Type 2 components
Heat treatment	Supplier/Manufacturer-defined	— COC (subcontractor) — Job lot results verification (supplier/manufacturer)	— COC (subcontractor) — Job lot results verification (supplier/manufacturer)
Component traceability	Supplier/Manufacturer-defined	Job lot traceable for Type 1 components	Job lot traceable for Type 1 components
Component dimensions	Supplier/Manufacturer-defined	Sampling plan	Sampling plan
Welding			
Type 1 welds	Supplier/Manufacturer-defined	Visual	Surface nondestructive examination (NDE) per sampling plan and visual
Type 2 welds	Supplier/Manufacturer-defined	Visual	Visual
Hardness			
Type 1 components	Supplier/Manufacturer-defined	Supplier/Manufacturer-defined	Per sampling plan
Type 2 components	Supplier/Manufacturer-defined	Supplier/Manufacturer-defined	Supplier/Manufacturer-defined
Component NDE			
Type 1 components	Supplier/Manufacturer-defined	Supplier/Manufacturer-defined	Surface NDE per sampling plan
Type 2 components	Supplier/Manufacturer-defined	Supplier/Manufacturer-defined	Supplier/Manufacturer-defined

Table 3—Quality Level Definitions (Continued)

Item	Quality Level		
	QL3	QL2	QL1
Shear devices	Supplier/Manufacturer-defined	Shear verification	Shear verification
Assembly/General			
Assembly verification	Supplier/Manufacturer-defined	Supplier/Manufacturer-defined	Supplier/Manufacturer-defined
Assembly traceability	Supplier/Manufacturer-defined	Supplier/Manufacturer-defined	Supplier/Manufacturer-defined
QC documentation	Supplier/Manufacturer-defined	Supplier/manufacturer-retained	Supplier/manufacturer-retained

6.4.2 Material

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

— a COC to the supplier/manufacturer stating that the material meets the supplier/manufacturer's documented specifications;

— an MTR to the supplier/manufacturer so that the supplier/manufacturer can verify that the material meets the supplier/manufacturer's documented specifications; or

— explosives, energetics, and explosive-containing devices shall have an equivalent certificate to the supplier/ manufacturer stating that the material meets the supplier/manufacturer's documented specifications; or report that the supplier/manufacturer can verify that the material meets the supplier/manufacturer's documented specifications.

6.4.3 Instrumentation

The supplier/manufacturer shall maintain a documented procedure for the control of testing, measuring, and monitoring equipment. Testing, measuring, monitoring, and detection equipment shall:

a) be calibrated against measurement standards;

b) have the calibration status identifiable by the user prior to and during use;

c) be safeguarded from adjustments or modification that would invalidate the measurement result or the calibration status;

d) be protected from damage and deterioration during handling, maintenance, and storage; and

e) be used under environmental conditions that are suitable for the calibrations, inspections, measurements, and tests being performed.

Equipment used for dimensional measurements shall be defined by the supplier/manufacturer.

6.4.4 Component Dimensional Inspection

6.4.4.1 All components shall be dimensionally inspected per a documented sampling plan.

6.4.4.2 Thread tolerances, inspection requirements, gauges, gauging practice, gauge calibration, and certification for connections shall conform to the documented thread specifications.

6.4.5 Quality Control Tests

The supplier/manufacturer shall establish any required QC testing methods and procedures.

6.4.6 Manufacturing Nonconformance

6.4.6.1 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 identification, documentation, evaluation, segregation (when applicable), and disposition of nonconforming assemblies or components.

6.4.6.2 The responsibility for review and authority for the disposition of nonconforming assemblies or components shall be defined by the supplier/manufacturer. Nonconforming assemblies or components shall be:

— a) reworked to meet the specified requirements;

— b) accepted with or without repair by concession; or

— c) rejected or scrapped.

6.4.6.3 Repaired and/or reworked assemblies or components shall be inspected in accordance with the requirements of the appropriate QL and the documented specifications of the supplier/manufacturer that are no less stringent than those used for new products.

6.4.7 Calibration Systems

6.4.7.1 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's procedures that are based on an internationally recognized standard. Technologies for inspections with verifiable accuracies equal to or better than those listed in this specification may be applied with appropriate documentation and when approved by a qualified person(s).

6.4.7.2 Calibration intervals for measuring and testing equipment shall be established based on repeatability and degree of usage. The calibration interval cannot be increased by more than twice the previous interval, which is not to exceed one year. Calibration standards used to calibrate measuring equipment shall be checked and approved at least once every three years by an independent outside agency with traceability to the applicable recognized national or international standards agency.

6.4.8 Personnel Qualifications

6.4.8.1 Personnel performing NDE shall be qualified in accordance with an international or national standard such as ASNT SNT-TC-1A or ISO 9712, Level 2 minimum for evaluation and interpretation.

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

6.4.8.3 All personnel performing inspections for acceptance shall be qualified per the supplier/manufacturer's documented specifications.

7. Redress and Repair

Redress activities for perforating tools after original manufacture shall be defined by the supplier/manufacturer's procedures.

Repair activities to perforating tools shall return the product to a condition meeting all requirements stated in this specification or the edition in effect at the time of original manufacture. Repaired products shall be marked with an "R" after the original manufacture date to indicate that the product has been repaired. Repairs shall be defined by the supplier/manufacturer's procedures.

Redress and repair shall apply to all reusable tools and components.

8. Shipment and Storage

8.1 General

8.1.1 Perforating tools shall be stored per the documented specifications of the supplier/manufacturer in order to prevent deterioration (caused by atmospheric conditions, debris, radiation) prior to transport.

8.1.2 Perforating tools and products shall be packaged for transport per the documented specifications of the supplier/ manufacturer in order to prevent normal handling loads and contamination from harming the equipment. The supplier/ manufacturer specifications shall address the protection of external sealing elements, sealing surfaces, and exposed threaded connections.

8.2 Shipping

8.2.1 Shipping requirements for specific or extreme handling and environments shall be defined by manufacturer/ supplier.

8.2.2 Any items classified as dangerous goods such as explosives shall be shipped according to local or international government laws and restrictions.

8.3 Shelf Life

8.3.1 General

The supplier/manufacturer shall define a product shelf life for elastomers and energetic materials as for the following conditions. All explosives, energetics, and other controlled items shall be stored according to local or international government laws and restrictions.

8.3.2 Original Packaging

The supplier/manufacturer shall provide a documented procedure for packaging, storage, and expected shelf life.

8.3.3 Opened Product

The supplier/manufacturer shall provide a documented procedure for re-packaging, storage, and resulting expected shelf life.

9. Service Center Requirements

9.1 Documentation and Data Control

9.1.1 The traceability and tracking of each assembly and component shall be controlled throughout the processing and shall conform to a documented procedure.

9.1.2 Each service center shall be supplied with the documentation by the supplier/manufacturer according to 6.2.2. All documentation and data control shall be reviewed and adhere to local laws and regulation specifically for export compliance rules.

9.1.3 The following documentation shall be available for review by a user/purchaser upon request:

a) serial number-specific documentation:

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

2) approved modification records;

3) service completion certificate.

b) generic documentation:

1) datasheet/technical specifications;

2) summary validation records;

3) job history (by tool model);

4) gun loading sheets;

5) firing heads (shear pins, burst discs);

6) explosive components by date shift code or other form of batch identification.

9.2 Records Retention

9.2.1 Records of each tool's status, use, repair, redress testing, and evaluations shall be retained in a record retention system that is accessible by the service center, conforming to the requirements of 6.2.1.

9.2.2 The service center shall provide access to the most recent repair, redress testing, and evaluation records to operational personnel.

9.3 Receiving Inspections for Newly Received Tools

9.3.1 When tools are received at a service center, either new or transferred, they shall be evaluated according to documented procedures by qualified personnel and the component parts evaluated as required by the supplier/

manufacturer.

9.3.2 The identification of each tool and component shall be recorded on an inspection report. This report shall be archived and included in each tool's use history as applicable.

9.4 Reusable Parts

A service center shall identify and inspect all reusable parts. Service life of these parts shall follow the supplier/ manufacturer's specification.

9.4.1 Drop Bars for firing heads

Drop bars shall be inspected for straightness and meet manufacturers' original requirements.
Any fishing neck shall be inspected for geometry and function.

9.4.2 Fit for Use

Reusable parts shall be inspected per manufacturer's instructions to determine fit for use. This should include:

a) Threads
b) Sealing areas
c) Electrical contacts
d) Signs of material loss
e) Cracking
f) Corrosion

9.5 Product Assembly

9.5.1 General

9.5.1.1 A service center shall perform assembly, redress, and maintenance of products according to documented procedures. Procedures shall meet requirements of the supplier/manufacturer for each specific tool and component.

9.5.1.2 Service center shall review the procedures to ensure adequacy and any translations to be understood by trained personnel. Operation procedures and product-related documentation shall be in the language that is understood by the operating personnel.

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

9.5.1.4 Inspections and testing shall be performed by a qualified person. The service center shall have documented procedure for any of the following testing and inspections:

— a) pre-run;

— b) post-job;

— c) periodic and post-severe service inspection;

— d) service; and

— e) function test.

9.5.1.5 Records of the testing and inspections shall be maintained.

9.5.2 Gun Loading/Assembly

9.5.2.1 The manufacturer's assembly procedures shall be followed during assembly and loading of guns.

9.5.2.1 A record of the assembled and loaded guns shall be available to the user/purchaser and shall contain the following information, where applicable:

— a) ensurance and a record that the appropriate explosive types are used in the assembly;

— b) compatible components, threaded connections, and seals;

— c) loaded and blank positions within each gun shall be recorded;

— d) traceability of all components of the detonation train (boosters, detonating cord, charges);

— e) identification of each gun shall be made by a unique identifier, and its location in the tools string shall be recorded;

— f) maintenance of transport caps and the ensurance they provide seal in wet environments (see API RP 67).

9.5.3 Firing Head Assembly

Firing heads shall be assembled per the manufacturer's procedures. Shear pinning sheets and calculations shall be documented and reviewed. All components of the detonation train (boosters, detonating cord, charges) shall be traceable. Explosive types shall be recorded and ensured to be compatible for the job application.

9.5.4 Cutter Assembly

9.5.4.1 The service center shall identify the original manufacturer and part number for all cutter assemblies and components.

9.5.4.2 There shall be traceability of all components of the initiation and detonation train, initiation and high-rate oxidation or combustion. Chemical type of cutters shall have traceability of the cylinder maintained and available.

9.5.5 Perforating Accessory Assembly

The tool manufacturer's assembly procedures shall be followed. A record of the assembled tools shall be available to the user/purchaser and shall contain the following information, where applicable:

— a) ensurance and a record that the appropriate explosive types are used in the assembly;

— b) compatible components, threaded connections, and seals;

— c) traceability of all components of the detonation train (boosters, detonating cord, charges).

9.6 Quality Control

The service center shall have a quality management system implemented that ensures the conformance to the requirements defined within this specification. The following service center quality records shall be maintained:

— a) Current maintenance and operating manuals and datasheets are used.

— b) Calibration of test equipment and tools shall conform to 6.4.7.

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

— d) Pressure test facilities comply to all applicable regulations.

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

— f) Inspection and maintenance checklists/reports and test reports shall be archived in accordance with the document retention policy in 6.2.

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

9.7 Personnel Qualification

9.7.1 Personnel performing inspection, testing, redress, and repair operations shall be trained and qualified in compliance with the documented supplier/manufacturer procedures. Additionally, personnel approving the interpretation of nondestructive testing (NDT) shall be qualified per ASNT SNT-TC-1A Level II or ISO 9712 Level II or an equivalent national or international standard.

9.7.2 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 6.4.7.

9.7.3 Qualified personnel shall have immediate access to all necessary records, such as diagrams, technical data, and instructions necessary to complete the designated work according to the requirements of the procedures.

9.8 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 the original specifications of the tool.

9.9 Design Revision Updates and Limitations

The service center shall implement design revisions that the supplier/manufacturer instructs as a mandatory change to the product. Service center modifications shall not be allowed unless expressly authorized and approved by the supplier/manufacturer. Service center modifications shall be documented in accordance with 9.2.

Annex A
(normative)

Steel Tubular Material for Perforating Gun Carriers

A.1 Material Technical Specification and Material Grades

A.1.1 Three product specification levels (PSLs) are introduced to give the perforating gun designer/manufacturer a choice of predefined sets of requirements with increasing restrictions. The requirements are intended to guide the steel manufacturer towards more stringent, consistent, and reliable products to cope with more severe well designs or operating conditions.

A.1.2 PSL1 tubular carriers have the lowest degree of requirements, imply the usage of lower strength steels, and are intended to be used in the less stringent well designs or operating conditions.

A.1.3 PSL2 tubular carriers have an intermediate degree of requirements, are not limited in steel strength, have more stringent chemical, destructive, and NDT requirements, and are intended for general use in well designs or operating conditions.

A.1.4 PSL3 tubular carriers have the highest degree of requirements, are not limited in steel strength, have the most stringent chemical, destructive, and NDT requirements, and are intended for more severe well designs or operating conditions.

A.1.5 Steel tubing used in the manufacture of perforating gun carriers shall be defined by a documented and traceable material technical specification (MTS).

A.1.6 The MTS shall define the required manufacturing process, heat treatment, chemical and mechanical properties, geometrical tolerances, and frequency of testing and NDE requirements, according to the requested product PSL, as appropriate.

A.1.7 Any additional or secondary heat treatments shall be documented.

A.1.8 The MTS may comprise one or more material grades, each one being suitable for certain gun systems, as per manufacturer design criteria.

A.1.9 The suitability of a certain material grade to a specific perforating gun system design is a responsibility of the perforating gun designer and shall be validated to the requirements in 5.5 and 5.7 of this specification.

A.1.10 The material grades defined in the MTS shall be in agreement with the minimum requirements listed in A.2 to A.5, according to the requested PSL.

A.2 Requirements for Steel Tubing Manufacturing Process and Heat Treatment

A.2.1 Steel tubing used in the manufacture of perforating gun carriers in agreement to this specification shall be made to a fine-grain practice. Steel made to a fine-grain practice may contain one or more grain-refining elements such as aluminum, niobium, vanadium, or titanium in amounts intended to result in the steel having a fine austenitic grain size.

A.2.2 Steel tubing shall be made by hot-finished welded or seamless process, and heat-treated full-body, full-length in accordance with a documented procedure, to achieve the required mechanical properties.

A.2.3 Cold-drawn or cold- formed seamless tubing shall have been full-body, full-length heat-treated after the cold forming operation. The specified full-body full-length heat treatment may be normalizing, normalizing and tempering, or quenching and tempering, as per Table A.1.

Table A.1—Manufacturing Process and Heat Treatment

Item	Product Specification Level		
	PSL1	PSL2	PSL3
Heat Treatment	Normalized, or normalized and tempered, or quench and tempered.	Normalized, or normalized and tempered, or quenched and tempered.	Quenched and tempered.
Straightening Methods	Gag-press or hot rotary-straightened, or cold rotary straightened	Gag-press or hot rotary-straightened, or cold rotary straightened followed by stress relief	Gag-press or hot rotary-straightened, or cold rotary straightened followed by stress relief

A.3 Requirements for Chemical Composition and Mechanical Properties

Steel tubing manufactured in accordance with this specification shall meet the requirements summarized in Table A.2, according to the required PSL.

Table A.2—Chemical Composition and Mechanical Properties

Item	Product Specification Level		
	PSL1	**PSL2**	**PSL3**
Steel chemical composition	Certificate of conformance or MTR showing conformance to a UNS, or chemical composition limits agreed between by the gun designer and the material supplier.	PSL1 plus: phosphorous P ≤ 0.020%; Sulfur S ≤ 0.005%.	PSL1 plus: phosphorous P ≤ 0.015%; Sulfur S ≤ 0.003%.
Clean Steel	No requirements	Test as per ASTM E45 Method A – informative results	Test as per ASTM E45 Method A. Limits defined by MTS
Austenitic grain size	No requirements	Test as per ASTM E112, result shall be 5 or finer	Test as per ASTM E112, result shall be 7 or finer
Tensile test	Tensile test according to ASTM E8 or ASTM A370. Limits defined by MTS	Tensile test according to ASTM E8 or ASTM A370. Limits defined by MTS	Tensile test according to ASTM E8 or ASTM A370. Limits defined by MTS.
Impact Toughness	No requirements	Charpy V-Notch test according to ASTM E23. Limits and condition defined by MTS. For welded pipes, the impact test specimen shall be machined with the notch at the weld heat affected zone.	Charpy V-Notch test according to ASTM E23. Limits and condition defined by MTS. For welded pipes, the impact test specimen shall be machined with the notch at the weld heat affected zone.
Hardness Test	Test ASTM E18, (Rockwell C, 1 quadrant, 9 readings), API 5CT Figure D.10. Hardness shall be lower than 23 HRC for this PSL only.[a]	Test ASTM E18, (Rockwell C, 1 quadrant, 9 readings), API 5CT	Test ASTM E18, (Rockwell C, 4 quadrants, 9 readings), API 5CT Figure D.10. Limits defined by MTS.

[a] The maximum hardness requirement applies to PSL1 as an approximation of minimum ductility and impact toughness requirements since those limits are not prescribed for this PSL level.

A.4 Requirements for Testing Frequency and Traceability

Steel tubing tested in agreement to this specification shall meet the minimum requirements summarized in Table A.3, according to the required PSL.

Table A.3—Testing Frequency and Traceability

Item	Product Specification Level		
	PSL1	PSL2	PSL3
Chemical Composition Testing Frequency	1 ladle analysis per heat	1 ladle analysis per heat. 2 product analysis per heat from two different tubular products.	1 ladle analysis per heat. 2 product analysis per heat hardness from two different tubular products.
Clean Steel Testing Frequency	Not applicable	1 test per heat/manufacturing lot	1 test per heat/manufacturing lot
Grain Size Testing Frequency	Not applicable	1 test per heat/heat treatment lot	1 test per heat/heat treatment lot
Tensile Testing Frequency	1 test per heat/ heat treatment lot	2 test per heat/heat treatment lot	3 test per heat/heat treatment lot
Charpy Impact Testing Frequency	Not applicable	1 test per heat/heat treatment lot	2 test per heat/heat treatment lot
Hardness Testing Frequency	1 test per heat/ heat treatment lot	2 test per heat/heat treatment lot	3 test per heat/heat treatment lot
Traceability	Material traceable to heat	Material traceable to heat and lot.	Material traceable to heat and lot.
A lot is defined as all those lengths with the same specified dimensions and grade, from the same heat of steel that are heat-treated as part of a continuous operation (or as an individual batch). When the quantity of tubes in a heat/heat treatment lot is less than the number of tests requested, only one test per tube shall be performed. Maximum number of tubes per lot shall be 200.			

A.5 Requirements for Nondestructive Examination

Steel tubing inspected in agreement to this specification shall meet the minimum requirements summarized in Table A.4, according to the required PSL.

Table A.4—Nondestructive Examination

Item	Product Specification Level		
	PSL 1	PSL 2	PSL 3
Location: Body			
Acceptable NDE Techniques	Eddy current (ASTM E309) or flux leakage (ASTM E570) or ultrasonic inspection (ASTM E213).	Eddy current (ASTM E309) or flux leakage (ASTM E570) or ultrasonic inspection (ASTM E213).	Ultrasonic inspection (ASTM E213)
Orientation	Longitudinal	Longitudinal and transversal	Longitudinal and transversal
Acceptance Criteria[a]	Defined by MTS	L2 for external surface L3 for internal surface	L2 for external surface L2 for internal surface
Wall Thickness Monitoring [b]	Not required	Required with 25 % surface coverage	Required with 100 % surface coverage
Location: Weld seam (if applicable)			

Table A.4—Nondestructive Examination (Continued)

Item	Product Specification Level		
	PSL 1	PSL 2	PSL 3
Acceptable NDE Techniques	Eddy current (ASTM E309) or flux leakage (ASTM E570) or ultrasonic inspection (ASTM E273)	Ultrasonic (ASTM E273) or radiographic inspection (ASTM E94/E94M or ASTM E2698 or ASTM E2033)	Ultrasonic (ASTM E273) or radiographic inspection (ASTM E94/E94M or ASTM E2698 or ASTM E2033)
Orientation	Longitudinal	Longitudinal and transversal	Longitudinal and transversal
Acceptance Criteria[a]	Electromagnetic and ultrasonic: L3 for external and internal surface	Ultrasonic: L2 for external surface L3 for internal surface Radiographic as per Tables E.5 and E.6 [c]	Ultrasonic: L2 for external and internal surface Radiographic as per Tables E.5 and E.6 [c]
Location: Pipe Ends (not inspected by automatic methods)			
Acceptable NDE Techniques	Manual or semiautomatic method such as eddy current (ASTM E309) or flux leakage (ASTM E570), or ultrasonic inspection (ASTM E213, ASTM E273, ASTM E164, ASTM E587) or radiographic inspection (ASTM E94/E94M or ASTM E2698 or ASTM E2033) or magnetic particle inspection (ASTM E709 or ASTM E3024/E3024M) or noninspected pipe ends shall be cut off		

[a] NDE ultrasonic or electromagnetic acceptance criteria level according to API 5CT 10th Edition, Table C.44/E.44.
[b] According to API 5CT 10th Edition, Section 10.13.4, plus additional requirements in Sections H.17.1 and H.17.2.
[c] NDE radiographic acceptance criteria according to API 5L 46th Ed., Annex E, Tables E.5, E.6.

Annex B
(normative)

Cutter Validation Requirements

B.1 Introduction

B.1.1 The purpose of this section is to describe recommended practices for evaluating pipe severing systems using tubular targets, ambient temperature, and hydrostatic pressure test conditions. The primary useful data output from these tests are:

a) The cut condition (complete, partial), shall be recorded for each iteration of the test. The reported percentage or remaining area in $in.^2$ may be related to tension or load to pipe.

b) Target condition (swell, flare) reported as maximum OD at widest point.

c) Recommended drift clearance diameter of tool for running in hole.

d) Characteristics of the debris and material type.

For example: small steel fragments <1/4 in. in diameter or small brass fragments <1/8 in. in diameter.

e) Witness casing condition.

f) Operational pressure.

g) Survival pressure.

h) Operating environment including fluid type (gas, water), and temperature.

B.1.2 The data produced shall be suitable for first order estimation of downhole performance.

B.1.3 Any other specific design validation for tool eccentricity, witness decentralization, target compression, combined temperature/pressure (if different from operational), low hydrostatic gas well, hydrostatic greater than 15 ksi, high nickel alloys, shall be specified.

B.2 Cutter Design Validation

B.2.1 V4 Cutter Supplier/Manufacturer

The supplier/manufacturer shall define a validation methodology.

B.2.2 V3 Cutter Supplier/Manufacturer

The supplier/manufacturer shall validate the tool with a methodology that at a minimum includes the following:

a) collapse pressure test at ambient temperature;

b) function test at ambient pressure and temperature:

   1) tool centralized;

   2) condition of cut (percentage, flare, split);

c) temperature limit(s) defined by explosive type and detonators;

NOTE Elastomeric O-rings can be tested to non-OEM recommended environment due to limited exposure time.

B.2.3 V2 Cutter Design Validation

The supplier/manufacturer shall conform to all requirements of V3 and the following additional requirements:

a) functional test at operational pressure and ambient temperature - condition of cut (percentage, flare, split);

b) debris (remnants size, magnetic, soft).

B.2.4 V1 Cutter Design Validation

The supplier/manufacturer shall conform to all requirements of V2 with the addition of testing with witness casing to evaluate boundary damage at operational pressure and ambient temperature.

B.2.5 V0 Cutter Design Validation

The supplier/manufacturer shall conform to all requirements of V1 with the addition of functional testing with witness casing at operational pressure and temperature.

B.3 Functional Test Target

B.3.1 General

B.3.1.4 The tests shall be conducted in a tubular target as illustrated in Figure B.1 using a full severing system and steel tubulars/casing.

B.3.1.2 The test setup can be lowered into a fluid-confined test area or in air, based on the desired wellbore fluid.

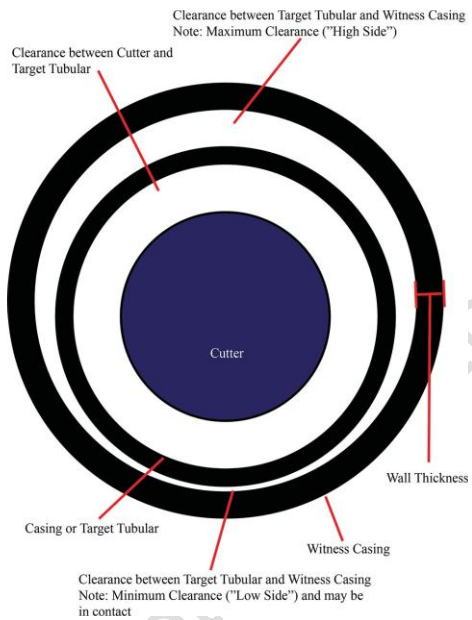

Figure B.1—Cutter Test Configuration

B.3.2 Target Documentation

B.3.2.1 All target material used in testing should have supporting documentation and/or material certificates to support that the casing material meets the requirements of the reported grade and material as prescribed in 6.4.2.

B.3.2.2 The supplier/manufacturer shall have a validation procedure for a tension and/or compression fixture if providing a test requiring tension or compression applied to target and/or witness assemblies.

B.3.3 Target Configuration

B.3.3.1 Witness

B.3.3.1.1 The shape of the witness casing form shall be cylindrical. Positioning of the tubing or casing within the witness shall be defined by the minimal radial clearance between the target and witness. The witness shall behave as an annular stand-off from the target tubular to simulate downhole interaction in deviated wellbores.

B.3.3.1.2 For tubular cutters, the target and witness shall be determined by Table B.1. Due to the variations that affect the operation of severing tools (colliding and slotted) the specific testing configuration shall be recorded.

Table B.1—Target and Witness

Target To Be Cut OD (in.)	Witness Casing		
	Weight (lb/ft)	OD (in.)	Wall Thickness (in.)
2.375	9.20	3.500	0.254
2.875	10.70	4.000	0.262
3.500	15.00	5.000	0.296
4.000	17.00	5.500	0.304
4.500	32.00	7.000	0.453
5.000	32.00	7.000	0.453
5.500	32.00	7.000	0.453
7.000	47.00	9.625	0.472
7.625	47.00	9.625	0.472
8.625	61.00	13.375	0.430
9.625	61.00	13.375	0.430
10.750	61.00	13.375	0.430
11.750	61.00	13.375	0.430
13.375	87.50	18.625	0.435
13.625	87.50	18.625	0.435

B.3.3.2 Target

Casing, tubing, and drill pipe grades to be used as the target and witness are shown in Table B.2 by size, OD.

Table B.2—Casing and Tubing for Use in Test Target

Target and Witness	Pipe Size, OD in.	Casing or Tubing API Grade
Tubing	2 3/8 – 4 1/2	P-110
Casing	5 – 13 5/8	P-110
Drill pipe	2 7/8 – 6 5/8	S-135
Witness	All	L-80

B.3.4 Severing System Selection

The severing system to be tested shall consist of standard field equipment, anchor if needed, and representative initiation mechanism. The initiation mechanism may be selected by the test facility as applicable.

B.3.5 Cutter Selection and Aging

The cutter system shall be selected from a production lot with traceability. The explosive and/or energetic components of the cutter system shall be stored for a minimum of 28 days prior to testing to allow some aging to occur. Detonators, initiators, and detonation cord is not included in the aging requirement. The test assembly shall be selected from one or more unopened expendable assemblies (cutter, charge, pellets, gas generator, or chemical cylinders). Reusable test assemblies shall be assembled with seals and redress components as defined by operating manual.

B.3.6 Test Fluid

Water shall be used as the test liquid. Dry gas system testing shall use air or nitrogen as appropriate for the testing conditions.

B.3.7 Shock Sensitivity

Mechanical shock sensitivity is not part of this qualification program.

B.3.8 Test Chamber Environment

The test chamber shall be sized to contain targets and cutting tool.

B.3.9 Confinement Vessel

B.3.9.1 General Design Guidelines

The design and operation of the pressure confinement vessel shall be left to the discretion of the individual testing company.

B.3.9.2 Pressure Capability Requirements

Due to the pressure generation nature of these cutter tools, special consideration for maximum pressure peaks should be considered in the use, design, and selection of vessels for the testing.

B.3.10 Test Conditions

The pressurizing test fluid used shall be as described in B.3.6. All tests will be conducted at temperature conditions defined by the validation level.

B.3.11 Test Sequence

B.3.11.1 The test chamber shall be filled with the fluid noted in B.3.6.

B.3.11.2 The test chamber shall be brought to the temperature as defined by the validation level for a minimum of one hour, as a thermal soak time for the test specimen to come to equilibrium. This test temperature shall be maintained throughout the pressure test.

B.3.11.3 The test chamber shall be pressurized to a minimum of 1.05 times the rated survival pressure of the cutting system. This pressure is to be maintained for one hour.

B.3.11.4 The pressure shall then be adjusted to the desired operating pressure and held for a minimum of five minutes after stabilization of the pressure. To be considered stabilized, the pressure shall remain constant with a variation of less than ±2 % of the test pressure over a five-minute period.

B.3.11.5 Activating the severing system to complete function test as defined by validation level.

B.3.12 Data Collection

B.3.12.1 General

The following measurements shall be made for each severing system evaluated:

a) Percentage of wall remaining that is capable of supporting a tensile load or force applied to the target. These values shall be recorded for each iteration of the test. The reported percentage or remaining area in square inches may be related to tension or load to part pipe.

b) Swell that is defined as the largest point measured on the diameter of the target after attempted cut.

c) Debris, including all solid materials, that is blown out of the device during activation or that is released by the device during the trip into the well, activation, or trip out of the well. This includes displaced or moved material from the target tubular (pipe, casing, tubing).

   NOTE This includes components that are designed to be acted upon by detonation, pressure, thermal energy, and materials displaced by differential pressures, flow, or gravity during the entire operation and conveyance.

d) Cutting tool integrity and swell after activation. Include condition of all parts that are retrieved.

e) Witness casing damage, as applicable for validation level, shall include:

   1) evaluation of partial cut or visual damage to the witness; and

   2) the percentage of the remaining cross-sectional area that is capable of supporting a tensile load or force applied to the target.

   These values shall be recorded for each iteration of the test.

f) Position of the witness casing to the target by the minimum radial clearance as tested.

B.3.12.2 Data Recording and Validity

Data shall be reported in the product data sheet for each system per 6.2.3.

B.3.13 Qualification

The system shall be tested at least twice as per the conditions of stated validation levels, and all tests shall be recorded.

B.3.14 Contingencies

In the event that the tool did not operate as intended (e.g., due to issues with the initiation system or other components of the test system), it will be necessary to troubleshoot according to local procedures.

If any change to the target (quantitative or qualitative) is observed, the target shall not be used for any testing under this section.

Annex C
(normative)

Validation Test Requirements for Perforating Guns

C.1 Introduction

The purpose of this section is to describe the validation requirements for perforating guns. Validation grades V3 to V0 provide a standard methodology for determining performance ratings of perforating guns.

C.2 Static Collapse Pressure

C.2.1 General

The intention of the methods described for V3 to V0 is to perform testing and evaluation to provide a safe operational pressure rating. It is advised to perform pressure testing without energetic or explosive materials present in the system. Simulated or inert substitutions may be used.

C.2.2 V4 Supplier/Manufacturer-defined

The supplier/manufacturer shall establish a collapse rating by a defined method. The method for collapse rating may be by testing, calculation, finite element analysis, or other recognized engineering practice that is documented.

C.2.3 V3 to V0 Single Collapse Test

C.2.3.1 General

The collapse test is a hydrostatic or liquid external pressure test. The collapse test shall be performed by at least one of the methods as described in C.2.3.3 or C.2.3.4

C.2.3.2 Test Requirements

C.2.3.2.1 The test shall be performed in a suitable pressure vessel with provisions for pressure, temperature, and time chart recorders. Calibration of testing equipment shall be in accordance with 6.4.7.

C.2.3.2.2 Materials for the gun system should satisfy engineering design and QC specifications as to metallurgy, chemical composition, physical properties, and dimensional properties.

C.2.3.2.3 Gun system length shall have a minimum unsupported section of eight diameters of nominal OD.

C.2.3.2.4 Systems that do not have internal components to provide structural support may have the internal components removed for the testing. If filler bars are used, they shall have a maximum OD at least 6.35 mm (0.25

in.) smaller than the inside diameter of the gun.

C.2.3.2.4 Seal dimensions should be adjusted to maximum extrusion gap for the test unless all seal configurations represented in the system have been separately qualified.

C.2.3.3 Collapse Pressure Test

C.2.3.3.1 General

This is a hydrostatic or liquid media external pressure test to failure. When conducting this test, the pressure where loss of pressure sealing or failure occurs shall be recorded. This actual collapse test pressure is then applied to an equation to calculate an operational pressure rating.

C.2.3.3.2 Collapse Test Temperature

The testing vessel shall be brought to the maximum rated temperature ±10 °F for a minimum one hour, as a thermal soak time for the test specimen to come to equilibrium. This test temperature shall be maintained throughout the pressure test.

C.2.3.3.3 Collapse Test Pressure

The test shall be conducted at a minimum of 1.05 times the rated operational pressure. The tested system shall hold the test pressure for a minimum of five minutes after stabilization of the pressure. To be considered stabilized, the pressure shall remain constant with a variation of less than ±2 % of the test pressure.

C.2.3.3.4 Actual Collapse Test Pressure

The test may be conducted in stages of increasing pressures with a minimum five-minute hold after stabilized pressure increment. If pressure stages are performed, then the last staged pressure held for five minutes prior to the specimen failure is considered the actual test pressure (P_{CA}) for the calculation of the operational pressure rating.

C.2.3.3.5 Determination Operational Pressure Rating

The supplier/manufacturer shall apply and document an industry-acceptable methodology for all calculations.

The operational pressure rating for a gun system shall be calculated as in Equation (1):

$$P_R = P_{CA} \times \frac{C_{LMC}}{C_A} \quad (1)$$

where

P_{CA} is the actual test pressure value that was held for the minimum prescribed time per C.2.3.3.4, in pounds per square inch (psi).

C_A is the calculated collapse value (or failure) of an actual gun test specimen to be evaluated based on its measured (actual) physical properties, dimensions, and seals in pounds per square inch (psi).

P_R is the operational pressure rating, the maximum to which the gun should be subjected in field service in pounds per square inch (psi).

C_{LMC} is the calculated collapse value (or permanent deformation) of a hypothetical gun sample under worst case conditions or “least material conditions” (LMC) of physical properties, dimensions, and seals, as permitted by design specifications and engineering drawings in pounds per square inch (psi

EXAMPLE Using the information in the foregoing examples the operational pressure rating P_R, would be calculated using Equation (2) as follows:

$$P_R = P_{CA} \times \frac{C_{LMC}}{C_A} = \qquad (2)$$

C.2.3.4 Adjusted Pressure Test Value—Proof Test Methodology

The method is to perform testing and evaluation should be as per API Recommended Practice 19B, 3rd Edition, Section 4.3.15 “Pressure Testing of the Gun System.”

— Pressure: At the adjusted pressure test value (±500 psi) with a minimum test pressure of 1.05 times the operational pressure rating;

— Temperature: At the operational temperature rating (±5.6 °C [±10 °F]);

— Duration: One hour at the adjusted pressure test value (P_{ATV}) and operational temperature rating for gun system;

— Determination of adjusted pressure test value (P_{ATV}).

Calculate the collapse of the gun body to be tested using those parameters required by recognized engineering practice such as API 5C3, 7th Edition. Calculate the collapse of the gun body at least material conditions (LMC) using specified physical and dimensional properties. Calculate the adjusted test pressure as in Equation (3):

$$P_{ATV} = \frac{C_A \times P_R}{C_{LMC}} \qquad (3)$$

where

P_{ATV} is the calculated adjusted pressure test value to which a specific gun sample is subjected that is equivalent to worst case conditions (minimum material conditions of physical properties, dimensions, and seals), taking into consideration the applicable manufacturing or service;

C_A is the calculated collapse value (or failure) of an actual gun specimen to be evaluated based on its measured (actual) physical properties, dimensions, and seals in pounds per square inch (psi).

P_R is the operational pressure rating, the maximum to which the gun should be subjected in field service in pounds per square inch (psi). (This value is related to C_{LMC} by the manufacturing or service company's assigned safety factor.);

C_{LMC} is the calculated collapse value (or permanent deformation) of a hypothetical gun sample under worst case conditions or "least material conditions" (LMC) of physical properties, dimensions, and seals, as permitted by design specifications and engineering drawings in pounds per square inch

(psi). (If C_{LMC} for a gun sample with lowest permissible yield strength, minimum permissible wall thickness, and maximum permissible seal gap).

EXAMPLE Using the information in the foregoing examples the adjusted pressure test value, P_{ATV}, would be calculated using Equation (4) as follows:

$$P_{ATV} = \frac{C_A \times P_R}{C_{LMC}} = \qquad (4)$$

C.2.3.5 Alternate Procedure for Verification of Adjusted Pressure Test Value

Where the computed collapse value is deemed not reliable, a gun body or minimum of six expendable charge cases shall be prepared and tested with materials taken uniformly from production run mill stock and verified or prepared to meet minimum physical and dimensional properties.

The gun body or expendable charge cases should be verified or prepared to meet minimum material conditions on all dimensions by careful machining with reference to the applicable engineering specifications. Tolerances for minimum material conditions shall be ±0.254 mm (±0.001 in.).

The gun body or expendable charges shall then be tested at a minimum test pressure of 1.05 times the operational pressure rating.

C.2.3.6 Collapse Pressure Service Factor

The collapse pressure service factor is the ratio of the calculated pressure rating for the raw material tubular (P_t) divided by the gun operational pressure rating (P_R) as defined in C.2.3. The collapse pressure service factor shall be listed on the product datasheet described in 6.2.3.

The calculated pressure rating of the raw material tubing (P_t) is derived by the method prescribed by Section 8 of API 5C3, 7th Edition.

C.3 Dynamic Survivability

C.3.1 General

C.3.1.1 The dynamic survivability testing exposes the gun system to the explosive detonation when the perforating system is fired/shot. The gun system shall be validated for each allowed variation of raw tubular material which includes the raw tubular material supplier/mill, OD size, and grade.

C.3.1.2 To validate a product family, a supplier/ manufacturer may use a worst-case system following the scaling limitations as described in 5.7.2.1. The external testing medium may be air or water. A system that is validated by shooting in air is also validated for water.

C.3.1.3 The gun system shall consist of an engineered design component that is fully loaded with shaped charges and any other energetic components for the system.

C.3.2 Test Pass/Failure Criteria

C.3.1.4 The pass/fail criteria shall be defined by the manufacturer/supplier.

C.3.3 V4 Supplier/Manufacturer-defined

The supplier/manufacturer shall establish a method for the dynamic survivability validation of a perforating gun system.

C.3.4 V3 Single Test with Nominally Loaded Charges

The supplier/manufacturer shall conduct the dynamic survivability test with a gun system fully loaded with charges that contain at minimum the explosive/energetic mass (net weight) of the production charge's nominal explosive load by design.

C.3.5 V2 Single Test with Overloaded Charges Defined by Manufacturer

The supplier/manufacturer shall conduct the dynamic survivability test with a gun system fully loaded with charges that contain an explosive/energetic mass (net weight) that are above the production charge's nominal explosive load by design. The explosive/energetic overloaded level may be defined by the manufacturer.

C.3.6 V1 Single test with 3 % Min. Overloaded Charges

The supplier/manufacturer shall conduct the dynamic survivability test with a gun system fully loaded with charges that contain an explosive/energetic mass (net weight) that are at least 3 % level over the production charge's nominal explosive/energetic load by design.

C.3.7 V0 Single Test with 5 % Min. Overloaded Charges

The supplier/manufacturer shall conduct the dynamic survivability test with a gun system fully loaded with charges that contain an explosive/energetic mass (net weight) that are at least 5 % level over the production charge's nominal explosive/energetic load by design.

C.4 Drop Testing of Perforating Gun System

C.4.1 General

The purpose of the drop test is to validate that a gun system will not be susceptible to distortion or buckling of components. Distortion or buckling of components is the movement, yielding, or dislocation of the gun system that may present a safety or a performance concern.

C.4.2 V4 Supplier/Manufacturer-defined

The supplier/manufacturer shall establish a method to validate that the perforating gun system is not susceptible to distortion or buckling of components that may cause a safety or performance concern.

C.4.3 V3 to V0 Drop Test Method

C.4.3.1 A gun system shall be dropped vertically (end-on) from a height of one foot onto a one-inch-thick ASTM A36/ A36M (or equivalent) steel plate supported by concrete as indicated in Figure C.1. The gun length shall be selected as the one with the longest unsupported internal structural member.

C.4.3.2 The gun system may be loaded with inert detonation cord and charges of equivalent weights. The ends of the gun may be closed with bull plugs or other standard connecting hardware designed specifically for the gun system. The gun may be constrained to prevent side tipping/falling post-initial impact from vertical drop.

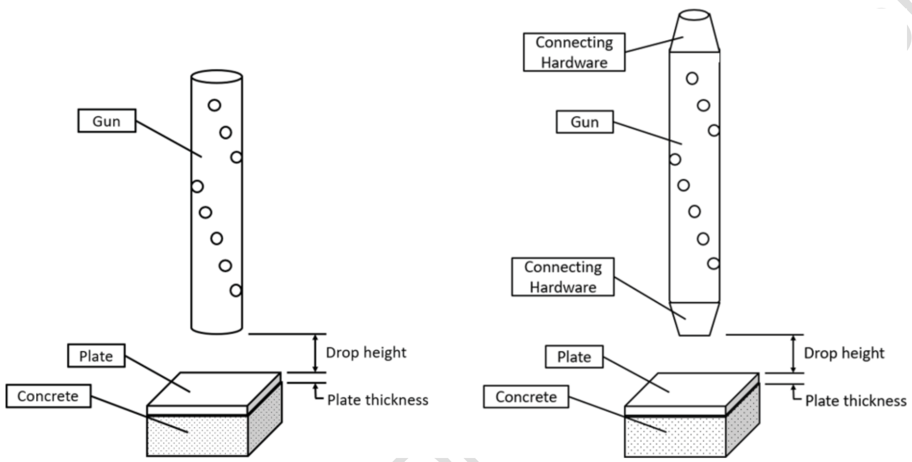

Figure C.1—Drop Test Schematic

The worst-case system configuration may be used to validate the product family. Worst-case system shall be identified by considering the strength of the internal components and the total mass load that applies to the internal components.

C.4.4 Drop Test Evaluation

The gun system drop test shall include the following evaluations, at a minimum:

– a) Post-drop, the system shall be opened by removing any end connection hardware that is attached to gun system.

– b) Measurements of the relative location of the internal end pieces shall be recorded pre- and post-drop.

– c) The relative location of the charges within the system shall be recorded pre- and post-drop.

– d) The condition of all explosive (or inert explosive) components shall be recorded.

– e) The condition of all structural or fastening components shall be recorded.

C.4.5 Drop Test Failure Criteria

C.4.5.1 A gun system is deemed to pass the drop test validation if it is determined that the system would still have performed as designed after the drop test.

C.4.5.2 Failure of drop test validation shall be indicated if the system is determined to not perform as designed after the drop test or if the explosive components would have presented a safety concern.

Annex D
(normative)

Validation Test Requirements for Firing Heads

D.1 Introduction

The purpose of this section is to describe the validation requirements for firing heads. Validation grades V3 to V0 provide a standard methodology for determining performance ratings of firing heads.

D.2 Pressure Ratings

D.2.1 General

The intention of the methods described is to provide standard methods for defining the critical pressure ratings for a firing head. Each pressure rating shall have an accompanying temperature rating.

Critical pressure ratings defined by tool functionality and performance are:

Operational Pressure: maximum external pressure which the tool will function.

Differential Pressure: difference between internal & external of tool.

Survival Pressure: maximum allowable pressure exposed to a tool during conveyance.

Safe Pressure Limit: maximum allowable pressure exposed to a tool without actuation.

These pressure ratings and the corresponding temperature ratings may not be based on explosive limits. Explosive limits such as time and temperature exposure should be provided by the supplier/manufacturer. API RP 67 should be referenced for matters related to explosive safety operations.

D.2.2 V4 Supplier/Manufacturer-defined

The supplier/manufacturer shall establish each pressure rating by a defined method. The method for pressure rating may be by testing, calculation, finite element analysis, or other recognized engineering practice that is documented.

D.2.3 Rating Methodology

D.2.3.1 V3 Calculated Rating

The rating shall be determined by the Von Mises calculation method at least material conditions and applying a Safety Factor equal to 1.2.

D.2.3.2 V2 Rating Method

The rating shall be determined by applying a Safety Factor of 1.2 to a tested pressure value at ambient temperature. (*Rating = Test value / S.F.)*

D.2.3.3 V1 Rating Method

The rating shall be determined by testing at a pressure and temperature with an applied Safety Factor of 1.0. (*Rating = Test value / S.F.)*

D.2.3.4 V0 Rating Method

The rating shall be determined as the test pressure with a safety factor of 1.1, and the test temperature with a safety factor of 1.05 applied. (*Rating = Test value / S.F.)*

D.2.4 V3 to V0 Test Methods

D.2.4.1 General

The ratings shall be determined by testing methods with applied conditions or factors prescribed for each validation grade.

D.2.4.2 Test Requirements

Commented [EP1]: The requirements were separated out.

D.2.3.2.1 The test shall be performed in a suitable pressure vessel with provisions for load or pressure, temperature, and time chart recorders. Calibration of testing equipment shall be in accordance with 6.4.7.

D.2.3.2.2 Materials for the firing head system shall satisfy engineering design and QC specifications as to metallurgy, chemical composition, physical properties, and dimensional properties.

D.2.4.3 Pressure Testing Methodology

D.2.4.3.1 General

Testing methodology for determining each of the critical pressure ratings shall be determined from the actual test values by applying the defined method.

D.2.4.3.2 Testing Temperature Requirements

The testing vessel shall be brought to the maximum rated temperature ±10 °F for a minimum one hour, as a thermal soak time for the test specimen to come to equilibrium. This test temperature shall be maintained throughout the pressure test.

D.2.4.3.3 Test Pressure requirements

The test shall be conducted at a minimum of 1.05 times the rated pressure value. The tested system shall hold the test pressure for the minimum time after stabilization of the pressure. To be considered stabilized, the pressure shall remain constant with a variation of less than ±2 % of the test pressure. The minimum hold or soak time for each pressure rating shall be:

- One hour for Survival Pressure
- One hour for Safe Pressure Limit
- Five minutes for Differential Pressure

- Five minutes for Operational Pressure

D.2.4.3.4 Test Pressure

The testing may be conducted as individual tests or in a single test with series of stages that meet the requirements of the Test Methodology and function the firing head.

The following provides an example that outlines how such a test may be performed.

Testing Criteria	Test Parameter	Method	Value	Rating
Pressure & Temperature	P1 & T1	Ps= P1 / (S.F.)	Ps, Ts	Survival Pressure
Soak for 1 hour		Ts= T1 / (S.F.)		
Pressure & Temperature	P1 & T1	PL= P1 / (S.F.)	PL, TL	Safe Pressure Limit
Soak for 1 hour		TL= T1 / (S.F.)		
Pressure & Temperature	P2 & T2	Pd = P2 / (S.F.)	Pd, Td	Differential Pressure
Min. hold 5 minutes		Td = T2 / (S.F.)		
Pressure & Temperature	P3 & T3	Po = P3 / (S.F.)	Po, To	Operational Pressure
Min. hold 5 minutes		T0= T3 / (S.F.)		
Actuate FH				

D.2.4.3.5 Determination Pressure Ratings from Testing

The pressure and temperature ratings for a firing head system shall be calculated by:

Rating = Actual Test Value / Safety Factor.

D.2.4.4 Actuation Load Rating

D.2.4.4.1 Validation Grades for Actuation Load Rating

Actuation Load Rating provides a minimum applied load to actuate the firing head. The firing head shall be tested to the prescribed actual load to confirm that the tool fires or delivers an output as designed to initiate the intended downhole tools.

V0	Function Test at load & 1.05x temperature
V1	Function Test & temperature
V2	Function Test at load
V3	Calculated by industry defined methodology
V4	Supplier / Manufacturer defined

Annex E
(informative)

Firing Head Classification (FHC)

E.1 Firing Heads

Firing Head Classification (FHCs) are introduced to give the designer/manufacturer a choice of predefined sets of requirements with increasing restrictions.

The requirements are intended to guide the user to align product requirements based on risk assessment, environment, well designs or operating conditions. Firing head safe functionality is critical in that the tool arms and fires to initiate the toolstring. The mechanism that arms and fires the firing head is defined as an action. Actions are characterized as independent or dependent actions.

Independent actions are independently applied and not dependent on each other. As an example, if A and B are independent actions then action A must occur, and action B must occur to actuate the firing head.
An illustration is if Temperature and Pressure limits are used as independent actions, then the prescribed temperature must be met and the prescribed pressure limit must be met in order for the tool to actuate.

Dependent actions are actions that are applied by dependent relationships to each other.
An example of dependent actions is a drop bar firing head. The impact of the drop bar is the first action which then results in the second action of shearing pins.

E.2 Level Requirements

A firing head system may include multiple components that are connected together to define the complete firing system. This may include a firing head tool with additional isolation barriers or actuating mechanisms which provide additional firing or arming actions. Such a system can be evaluated to be an FHC.

FHC1 single action
FHC2 more than one dependent actions
FHC3 2 independent actions
FHC4 >2 independent actions to arm & fire.

E.3 Firing Head Actions

E.3.1 Actions – the mechanism that arms and fires the firing head to initiate the tool string.

Some typical firing head actions that are used in the industry include the following:

- Pressure,
- Temperature,
- Force Impact,
- Location,
- Voltage or amperage,
- Sonic signal.

This list is not all inclusive and is only provided as means to provide a clarification of the definition of actions related to firing head systems.

E.3.2 Independent Actions – actions that are independently applied and not dependent on each other.

A & B must occur → actuated
Temperature & Pressure limit

E.3.3 Dependent Actions – actions that are applied by dependent relationship to each other.

A → B → C → actuated
Impact then shear
Pressure then shear
Pressure signals / pulses
Translation of motion: longitudinal to rotational

The following is a simple example with graphic representation of a common type of firing head to illustrate the actions.

Figure E.1 to E.4 shows examples of Hydraulic Firing Head.

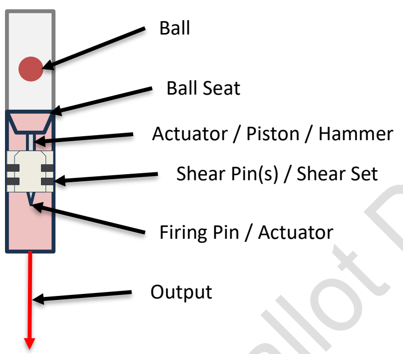

Figure E.1

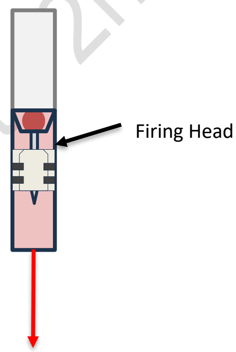

Figure E.2

In the example above, the hydraulic firing head provides three dependent actions:

a) First a Ball is dropped to seat inside the firing head.
b) Second, pressure is applied against the seated ball.
c) Third, the shearing of pins or shear set that moves the firing pin or actuator.

- Dependent Actions:

FHC 2

- A → B → C → actuated
- Drop Ball → Pressure → Shear → actuated

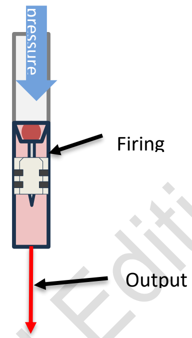

Figure E.3

The next illustration demonstrates an independent action. The independent action in this example is established by adding a temperature isolation barrier to the same hydraulic firing head.

- Adding an Independent Action:

FHC 3

- (A → B → C) → **&** D must occur → actuated
- (Drop Ball → Pressure → Shear) → & Temperature → actuated

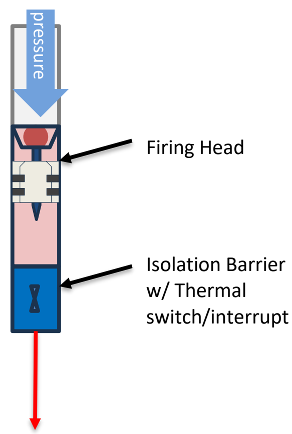

Figure E.4

The firing head system now has two independent actions and three dependent actions.

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