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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, as defined herein, for use in the petroleum and natural gas industry.

This specification provides the requirements for reporting and validating operational ratings of downhole perforating tools that are not addressed by any current standards or specifications. Thus:

- Providing well-defined operational ratings for functionality of downhole perforating tools as provided by the supplier/manufacturer.
- Defining levels of quality control for downhole perforating tools including validation requirements, acceptance testing, performance rating envelopes and service center requirements.

2 Normative References

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

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

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

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

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

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

ASQ Z1.4, *Sampling Procedures and Tables for Inspection by Attributes*

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

ASTM E213, *Standard Practice for Ultrasonic Testing of Metal 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*

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ISO2859-1, *Sampling procedures for inspection by attributes – Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection*

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

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

NACE MR0175/ISO 15156, *Petroleum and natural gas industries - Materials for use in H₂S-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 terms and definitions given in ISO 9000 and the following apply.

3.1.1

Assembly

Product comprised of more than one component.

3.1.2

Carrier

A component of a perforating gun assembly that houses the internal components such as shaped charges, detonation cord, charge holders and other items. 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

Differential Pressure

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

3.1.4

Downhole Perforating Tools

Assemblies, components, and parts that are used to convey, initiate, detonate, actuate, retain, anchor, and release the perforating tool string. Perforating Tools as defined in this document includes cutters and severing tools.

3.1.5

Energetics

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

3.1.6

Firing Head

Device used to initiate the detonation as related to downhole operations.

3.1.7

Model

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

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3.1.8

Operating Manual

Publication issued by the manufacturer, which contains detailed data and instructions related to the design, storage, installation, operation and maintenance of equipment.

3.1.9

Operational Pressure

The maximum external pressure that equipment will perform under normal operating conditions.

3.1.10

Perforating Gun

Device used to perforate oil and gas wells utilizing shaped explosive charges.

3.1.11

Pipe Recovery Cutter

Device which intentionally cuts or severs oilfield tubulars and drill pipe using expelled material. These include explosive (jet), thermite and chemical. This specification does not include mechanical, abrasive and water jet.

3.1.12

Product family

A group of assemblies where the same design configuration principles apply to materials, geometry, and functionality.

3.1.13

Qualified person

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

3.1.14

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.

3.1.15

Shot Density

The number of shots per unit of length.

3.1.16

Size

Relevant dimensional characteristics of the equipment as defined by the supplier/manufacturer. Perforating gun sizes are defined by nominal OD dimension of carrier tubing.

3.1.17

Spacer

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

3.1.18

Test Pressure

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

3.1.19

Type

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

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3.1.20

Type 1 component or weld

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.

3.1.21

Type 2 component or weld

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 for materials

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/manufacture'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):

- perforating gun
- pipe recovery cutter
- conveyance connectors
- booster
- firing head

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- gun anchor/hanger
- release tool
- setting tool

4.3 Well Parameters

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

- dimensions, material, and grade of the casing and tubing;
- end connections;
- well angle from the vertical;
- deviations and restrictions product must pass through;
- configuration of tubing (single or multiple strings)
- location and orientation of other lines (electrical, hydraulic, fiber-optic)
- relationship of the perforating tool with other well devices, tubing, casing by means of a well schematic drawing, if applicable;
- expected minimum and maximum values of production or injection pressures, pressure differentials, changes in temperatures, and flow rates;
- maximum pressure;
- maximum temperature;
- maximum expected time at temperature and pressure;
- wellbore fluids and/or gases;
- known conditions of well structure or equipment such as scaling, paraffins, NORM, corrosion.
- Depth of zones and correlation process (short joints, radioactive markers...)
- any other relevant well parameter(s).

4.4 Operational Parameters

The user/purchaser should specify the following operational parameters:

- installation method, including conveyance method;
- activation method and number of times activated or manipulated;
- equipment operating depth (setting, activating or firing);
- retrieving method;
- representative well schematic;
- well pumping operations including fluids and solids composition, flow rates, and exposure time;
- 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;

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- expected activation temperature and anticipated temperature profile, exposure time during well operations and completion processes;
- size, type, and configuration of devices to be run through or over the perforating tools;
- 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 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 in the purchase order or request for services.

4.6 Compatibility with Related Well Equipment

The user/purchaser should identify the following:

- 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;
- internal receptacle profile(s), bore dimension(s), OD, ID, and the respective locations;
- configuration of other products and conduits to be used in connection with this product including material, size and type.
- 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 quality control (QC), as defined in 6.4.1.

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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 following criteria shall be met:

- the product shall perform in accordance with the functional specification during installation, activation, operation, and retrieval.
- where applicable, the product shall not compromise well intervention operations.

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.

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;

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- 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 as the 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. For perforating tools validated to grades V4 through V0, a rated performance envelope is also required.

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 all conveyance, operational, removal methods and tools, contingency, and 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 utilized 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

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grade specifics are defined in applicable annexes. The supplier/manufacturer shall meet the validation test requirements of Table 1 to the selected validation grade.

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. 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. 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. 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.

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 Validation by Design Calculation

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 to the tool's pressure rating at ambient temperature. Validation by design calculation is limited to V2.
- b) Validation for V3 to V1 Design calculation methodology per these industry standards or another industry acceptable engineering practices.
 - 1) ACME & 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 & Casing Threads per API 5B
 - 4) Any other thread types (including proprietary) shall have a defined methodology by the manufacturer.

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

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

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

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.

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Table 1—Summary of Design Validation Grades

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, Functional Test at ambient Pressure and Temperature
V2	Single Collapse Test	Single test with over-loaded 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. over loaded 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. over loaded 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 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 Functionalities Not Addressed in Table 1

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.

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5.6 Design Changes

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.

The supplier/manufacturer shall, as a minimum, consider the following:

- stress levels of the modified or changed components;
- material changes;
- functional changes.

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

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.

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

The supplier/manufacturer shall establish the maximum stress within the previously validated 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.

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

The limitations for scaling perforating guns are:

- a) OD: changes in OD that affects the minimum or maximum material conditions would require validation.
- b) Wall thickness: reduction of minimal wall thickness would require validation.

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- 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 load 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.

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 versus RDX charges or other explosive materials.

5.7.2.2 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

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

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

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.

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 5 years from date of manufacture or repair. These shall be available and auditable by the user/purchaser.

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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:

- manual reference number;
- parts list;
- operational procedures and related tools;
- pre-installation inspection procedures;
- representative drawing showing major dimensions (ODs, IDs, and lengths);
- troubleshooting;
- installation instructions;
- field testing instructions;
- requirements for handling, shipment, and storage;
- 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:

- name of supplier/manufacturer;
- product size, type, and model
- manufacturer product number;
- manufacturer product name;
- metallic materials;
- nonmetallic materials;
- minimum ID;
- OD;
- overall length;
- temperature range;
- temperature cycle range;
- disconnect ratings;

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- disconnect unloading pressure;
- number of disconnects;
- disconnect load;
- (re)connect ratings;
- (re)connect temperature;
- number of (re)connects;
- rated performance envelope for V1 through V0;
- shear device min and max values;
- internal and external differential pressure ratings;
- tensile load ratings;
- top connection(s);
- bottom connection(s);
- casing or tubing range, size, and mass and/or minimum and maximum casing or tubing IDs;
- maximum conveyance OD, inclusive of running/repositioning equipment;
- maximum retrieval OD, inclusive of post detonation or equipment;
- conveyance and retrieval, tools;
- any other rated functionalities (5.5.3.2);
- quality level;
- design validation grade;
- operating manual reference number.

6.3 Product Identification

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

- supplier/manufacturer identification;
- supplier/manufacturer product number;
- date of manufacture (mm/yy) or equivalent method to identify the date of manufacture;
- quality level;

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- design validation grade.
- for QL1, a unique serial and traceability number.

6.4 Quality Requirements

6.4.1 General

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

The supplier/manufacture 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	COC or MTR	MTR for Type 1 components COC or MTR for Type 2 components
Non-metallic 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 NDE per sampling plan and visual
Type 2 welds	Supplier/Manufacturer defined	Visual	Visual
Hardness			
Type 1	Supplier/Manufacturer defined	None	Per sampling plan

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compo- nents			
Type 2 compo- nents	Supplier/Manufacturer defined	None	None
Component NDE			
Type 1 compo- nents	Supplier/Manufacturer defined	None	Surface NDE per sampling plan
Type 2 compo- nents	Supplier/Manufacturer defined	None	None
Shear de- vices	Supplier/Manufacturer defined	Shear verification	Shear verification
As- sem- bly verifi- cation	Supplier/Manufacturer defined	None	Internal pressure test, ID drift
As- sem- bly trace- ability	Supplier/Manufacturer defined	None	None
QC documenta- tion	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 certificate of compliance (COC) to the supplier/manufacturer stating that the material meets the supplier/manufacturer’s documented specifications; or
- a material test report (MTR) to the supplier/manufacturer so that the supplier/manufacturer can verify that the material meets the supplier/manufacturer’s documented specifications.
- 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

Instrumentation shall meet the following requirements unless additional requirements are required in another section of this document.

- Automatic controlling and recording instruments shall be used.
- Thermocouples shall be located in the furnace working zone(s) and protected from furnace atmospheres.

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- The controlling and recording instruments used for the heat treatment processes shall possess an accuracy of ± 1 % of their full-scale range.
- Temperature controlling and recording instruments shall be calibrated at least once every 3 months until a documented calibration history can be established. Calibration intervals shall then be established based on repeatability, degree of usage, and documented calibration history.
- Equipment used to calibrate the production equipment shall possess an accuracy of ± 0.25 % of full-scale range.
- Equipment used for dimensional measurements shall be defined by the supplier/manufacturer.

6.4.4 Component Dimensional Inspection

All components shall be dimensionally inspected per a sampling plan that meets the requirements of an international or national standard such as ISO2859-1 or ASQ Z1.4.

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

6.4.5 Quality Control Tests

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

6.4.6 Manufacturing Nonconformance

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.

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:

- reworked to meet the specified requirements, or
- accepted with or without repair by concession, or
- rejected or scrapped.

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

6.4.7 Calibration Systems

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, such as ISO/IEC 17025. 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). 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 1 year. Calibration standards used to calibrate measuring equipment shall be checked and approved at

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least once every 3 years by an independent outside agency with traceability to the applicable recognized national or international standards agency.

6.4.8 Personnel Qualifications

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.

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.

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

7 Redress and Repair

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

This requirement shall apply to all reusable tools and components including, but not limited to: tandems, connectors, shock absorbers.

This requirement may not apply to accessory equipment that is not part of the perforating tool including, but not limited to: cable heads, weight bars, centralizers.

8 Shipment and Storage

8.1 General

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

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

8.2 Shipping

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

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

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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

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

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.

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

- a) Serial number specific documentation
 - Shear/burst device testing records (where applicable).
 - Maintenance records.
 - Approved modification records.
 - Service completion certificate.
- b) Generic documentation
 - Datasheet/technical specifications.
 - Performance envelope.
 - Summary validation records.
 - Job history (by tool model).
 - Gun loading sheets
 - Firing heads (shear pins, burst discs...)

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- Explosive components by date shift code or other form of batch identification.

9.2 Records Retention

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. The service center shall be able to provide, as a minimum, access to the most recent repair, redress testing, and evaluation records to operational personnel.

9.3 Receiving Inspections for Newly Received Tools

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. Each tool's identification and the component's unique identification shall be recorded on an inspection report. This report shall be archived and included in each tool's use history 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 recommendation.

9.5 Product Assembly

9.5.1 General

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 components. 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.

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

Inspections and testing shall be performed by a qualified person. The service center shall have documented procedure and record for any pre-run, post job and periodically (and post severe service) inspection, service, and function test.

9.5.2 Gun Loading / Assembly

The manufacturers assembly procedures shall be followed during assembly and loading of guns. A record of the assembled and loaded guns shall be available to the user/purchaser, and shall contain the following information, where applicable:

- Ensure and record that the appropriate explosive types are used in the assembly.
- Compatible components, threaded connections, and seals.
- Loaded and blank positions within each gun shall be recorded.
- Traceability of all components of the detonation train (boosters, detonating cord, charges).

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- Each gun shall be identified by a unique identifier and its location in the tools string shall be recorded.
- Transport caps shall be maintained and ensured to 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. Traceability of all components of the detonation train (boosters, detonating cord, charges). Explosive types shall be recorded and ensured to be compatible for the job application.

9.5.4 Cutter Assembly

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

- Ensure and record that the appropriate explosive types.
- Compatible components, threaded connections, and seals.
- 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. As a minimum, the following are required for the service center quality records.

- Use current maintenance and operating manuals and datasheets.
- Calibration of test equipment and tools shall conform to 6.4.7.
- Training and competency certification of personnel is maintained and auditable.
- Pressure test facilities comply to all applicable regulations.
- Inspection and maintenance checklists/reports and test reports shall be signed by a qualified person other than the person performing the functions.
- Inspection and maintenance checklists/reports and test reports shall be archived in accordance with the document retention policy in 6.2.
- Replacement components shall conform to the requirements applied to the original component parts.

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9.7 Personnel Qualification

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

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

9.8 Repair

Repair of tools and related equipment shall be conducted according to procedures established by the supplier/matrix 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 mandatory design revisions as provided by the supplier/matrix manufacturer. Service center modifications are not allowed unless expressly authorized and approved by the supplier/matrix manufacturer. Service center modifications shall be documented in accordance with 9.2.

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Annex A (normative)

STEEL TUBULAR MATERIAL FOR PERFORATING GUN CARRIERS

A.1 MATERIAL TECHNICAL SPECIFICATION AND MATERIAL GRADES

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

The MTS shall define the required manufacturing process, heat treatment, chemical and mechanical properties, geometrical tolerances, frequency of testing and nondestructive examination requirements, according to the requested product specification level (PSL), as appropriate.

Any additional or secondary heat treatments shall be documented.

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

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 section 5.5 and 5.7. of this specification.

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

A.2 MINIMUM REQUIREMENTS FOR STEEL TUBING MANUFACTURING PROCESS AND HEAT TREATMENT

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.

Steel tubing shall be made by hot-finished welded or seamless process, heat treated full-body, full-length in accordance to a documented procedure, to achieve the required mechanical properties. 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
Yield Strength Limitation	Actual Yield Strength lower than 80ksi (551 MPa)	Actual Yield Strength lower than 160ksi (1102 MPa)	No limitation
Tube forming process	Welded or seamless	Seamless	Seamless

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Heat Treatment	Normalized, Normalized and Tempered, or Quench & Tempered.	Quenched & Tempered.	Quenched & Tempered.
Straightening requirements	Gag-press, Hot Rotary Straightened, Cold Rotary Straightened	Gag-press, Hot Rotary Straightened, Cold Rotary Straightened followed by Stress Relief	Gag-press or Hot Rotary Straightened, Cold Rotary Straightened followed by Stress Relief

A.3 MINIMUM REQUIREMENTS FOR CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES

Steel tubing manufactured in agreement to 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
Yield Strength Limitation	Actual Yield Strength lower than 80ksi (551 MPa)	Actual Yield Strength lower than 160ksi (1102 MPa)	No limitation
Steel Chemical Composition	Certificate of Conformance or MTR showing conformance to a unified numbering system 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 [but actual Yield Strength must be lower than 80ksi (551 MPa)]	Tensile test according to ASTM E8 or ASTM A370. Limits defined by MTS [but actual Yield Strength must be lower than 160ksi (1102 MPa)]	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.	Charpy V-Notch test according to ASTM E23. Limits and condition defined by MTS.

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Hardness Test	No Requirements	test ASTM E18, (Rockwell C, 1 quadrant, 9 readings), API 5CT figure D.10. Limits defined by MTS.	test ASTM E18, (Rockwell C, 4 quadrants, 9 readings), API 5CT figure D.10. Limits defined by MTS.
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A.4 MINIMUM 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/manufacturing lot	1 ladle analysis per heat 2 product analysis per heat/manufacturing lot
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	Not applicable	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 which are heat-treated as part of a continuous operation (or as an individual batch).
Maximum number of tubes per lot shall be 200.

A.5 MINIMUM 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		
	PSL1	PSL2	PSL3

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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
WT Monitoring ^b	Not required	Required with 25% surface coverage	Required with 100% surface coverage
<p>a NDE acceptance criteria level according to API 5CT 10th Ed., table C.44 / E.44</p> <p>b According to API 5CT 10th Ed., section 10.13.4, plus additional requirements in H.17.1 and H.17.2</p>			

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Annex B **(Normative)**

Cutter Validation Requirements

B.1 Introduction

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:

- Cut condition
- 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. The reported percentage or remaining area in in.² may be related to tension or load to part pipe.
- Target condition (swell, flare) as maximum OD at widest point
- Offset (restriction ratio)
- Offset (restriction ratio) min. running ID or restriction or required clearance inside the diameter that the tool must pass. Recommended 1/8 in. diametrical clearance. 1/16 in. diametrical clearance for a nipple or passing restriction of less than 18 inches of length.
- Debris
- Characteristic of the debris and material type.

For example: explosive cutters will leave tool steel in small fragments <1/4 inch diameter fragments of varying sizes. Occasional small brass pieces < 1/8 inch.
- Witness casing condition
- Operational pressure the hydrostatic pressure during the operation of the cutting tool stated performance.
- Survival pressure the maximum pressure exposed to tool during conveyance.
- Operating environment fluid environment including temperature (gas, water...)

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

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 15ksi, high nickel alloys, etc. will need to be specified on the purchase order.

B.2 Cutter Design Validation

B.2.1 V4 Cutter Supplier/manufacturer

The supplier/manufacturer shall define a validation methodology.

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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
- d) Elastomeric O-rings can be test to non-OEM recommended temperatures due to limited exposure time

B.2.3 V2 Cutter Design Validation

The supplier/manufacturer shall consist of all requirements of V3 and the following additional requirements.

- a) Functional Test at operational pressure and ambient temperature
 - 1) Flare (condition of the cut, i.e. flare and split)
- b) Tool centralized
- c) Debris (remnants size, magnetic, soft)

B.2.4 V1 Cutter Design Validation

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

B.2.5 V0 Cutter Design Validation

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

B.3 Functional Test Target

B.3.1 General

The tests shall be conducted in a tubular target as illustrated in Figure B.1. The test shall be conducted utilizing a full severing system and steel tubulars/casing. The test setup can be lowered into a fluid confined test area or in air, based on the desired wellbore fluid.

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	2-3/8	2.375	3-1/2	9.20	3.500	0.254	0.309	0.617
	2-7/8	2.875	4	10.70	4.000	0.262	0.301	0.601
	3-1/2	3.500	5	15.00	5.000	0.296	0.454	0.908
	4	4.000	5-1/2	17.00	5.500	0.304	0.446	0.892
	4-1/2	4.500	7	32.00	7.000	0.453	0.797	1.594
	5	5.000	7	32.00	7.000	0.453	0.547	1.094
	5-1/2	5.500	7	32.00	7.000	0.453	0.297	0.594
	7	7.000	9-5/8	47.00	9.625	0.472	0.841	1.681
	7-5/8	7.625	9-5/8	47.00	9.625	0.472	0.528	1.056
	8-5/8	8.625	13-3/8	61.00	13.375	0.430	1.945	3.890
	9-5/8	9.625	13-3/8	61.00	13.375	0.430	1.445	2.890
	10-3/4	10.750	13-3/8	61.00	13.375	0.430	0.883	1.765
	11-3/4	11.750	13-3/8	61.00	13.375	0.430	0.383	0.765
	13-3/8	13.375	18-5/8	87.50	18.625	0.435	2.190	4.380
	13-5/8	13.625	18-5/8	87.50	18.625	0.435	2.065	4.130

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 & 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 severing system shall be selected from a production lot with traceability. The severing system shall be stored for a minimum of 30 days prior to testing to allow some aging to occur. The test assembly shall be se-

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lected 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 fluid. 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. Three shots are required at each operational pressure, and all shots shall be recorded.

B.3.11 Test Sequence

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

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.

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.

The pressure shall then be adjusted to the desired operating pressure and 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 $\pm 2\%$ of the test pressure over a five-minute period.

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

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As residue explosives are reported to be found within the test fluid following detonation of the system, the entirety of the test fluid volume containing the residue, intact explosive material must be handled as an explosive material for any post-test handling/removal/disposal.

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 defined as the largest point measured on the diameter of the target after attempted cut.
- c) Debris which shall include all solid materials that are blown out of the device during activation, or that are released by the device during the trip into, 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 evaluation of partial cut or visual damage to the pipe or tubular outside the target. 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. The reported percentage or remaining area in square inches that may be related to tension or load to part pipe.

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 twice as per the conditions of stated validation levels.

B.3.14 Contingencies

In the event that the tool did not operate as intended (e.g. due to issues with 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 noted, the target shall be deemed unsuitable for any testing under this section.

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Annex C (normative)

Validation Test Requirements for Perforating Guns

C.1 Validation Test Requirements for Perforating Guns

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 this 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

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. Materials for the gun system should satisfy engineering design and quality control specifications as to metallurgy, chemical composition, physical properties, and dimensional properties. Gun system length shall have a minimum unsupported section of eight diameters of nominal outside diameter. 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 outside diameter at least 0.25 in. (6.35 mm) smaller than the inside diameter of the gun. 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.

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C.2.3.3.2 Collapse Test Temperature

The testing vessel shall be brought to the maximum rated temperature $\pm 10^{\circ}\text{F}$ 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 $\pm 2\%$ 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:

$$\text{Pressure Rating} = P_{CA} \times \frac{C_{LMC}}{C_A} \tag{1}$$

where

P_{CA} is the actual test pressure value that was held for the minimum prescribed time per C.2.2.2.3, 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). (For example, the calculated collapse value for a specific gun specimen can be 24,500 psi, however, this value could drop as low as 21,000 psi under minimum material conditions on other production runs.)

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. For example, for a gun rated at 20,000 psi, the C_{LMC} , is 21,000 psi, providing the safety factor is 1.05.)

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 is calculated to be 21,000 psi, it has an assigned operational pressure rating (P_r) of 20,000 psi providing the safety factor is 1.05.)

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

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$$P_R = P_{CA} \times \frac{C_{LMC}}{C_A} = \frac{24,500 \times 20,000}{21,000} = 23,333 \text{ psi} \quad (2)$$

C.2.3.4 Adjusted Pressure Test Value - Proof Test Methodology

The intention of this method is to perform testing and evaluation as per API-RP19B "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 ($\pm 10^\circ\text{F}$ [$\pm 5.6^\circ\text{C}$]).
- Duration: one hour at the adjusted pressure test value (P_{ATV}) and operational temperature rating for gun system.
- Determination of Adjusted Pressure Test Value

Calculate the collapse of the gun body to be tested using those parameters required by recognized engineering practice such as API 5C3. 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:

$$P_{ATV} = \frac{C_A \times P_r}{C_{LMC}} \quad (3)$$

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 company's safety factor, in pounds per square inch (psi).

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). (For example, the calculated collapse value for a specific gun specimen can be 24,500 psi, however, this value could drop as low as 21,000 psi under minimum material conditions on other production runs.)

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. For example, for a gun rated at 20,000 psi, the C_{LMC} , is 21,000 psi, providing the safety factor is 1.05.)

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 is calculated to be 21,000 psi, it has an assigned operational pressure rating (P_r) of 20,000 psi providing the safety factor is 1.05.)

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

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$$P_{ATV} = \frac{C_A \times P_r}{C_{LMC}} = \frac{24,500 \times 20,000}{21,000} = 23,333 \text{ psi} \quad (4)$$

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 ± 0.001 in. (± 0.254 mm). 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) would be derived by the method prescribed by the "External Pressure Resistance" in API-5C3.

C.3 Dynamic Survivability

C.3.1 General

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. A supplier/manufacture may use a system of worst-case as described in 5.7.2.1. to validate a product family. The external testing medium may be air or water. A system that is validated by shooting in air is also validated for water. 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

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

C.3.3 V4 Supplier/ manufacturer- defined

The supplier/manufacture 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/manufacture 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 charges nominal explosive load by design.

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C.3.5 V2 Single test with over-loaded 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 charges nominal explosive load by design. The explosive/energetic over-loaded level may be defined by the manufacturer.

C.3.6 V1 Single test with 3% min. over loaded 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 percent level over the production charges nominal explosive/energetic load by design.

C.3.7 V0 Single test with 5% min. over loaded 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 percent level over the production charges 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 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 for the validating the perforating gun system will not be susceptible to distortion or buckling of components that may cause a safety or performance concern.

C.4.3 V3 to V0 Drop Test Method

A gun system shall be dropped vertically (end-on) from a height of one foot on to a one-inch thick ASTM A36 (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. 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 design specifically for the gun system. The gun may be constrained to prevent side tipping/falling post initial impact from vertical drop.

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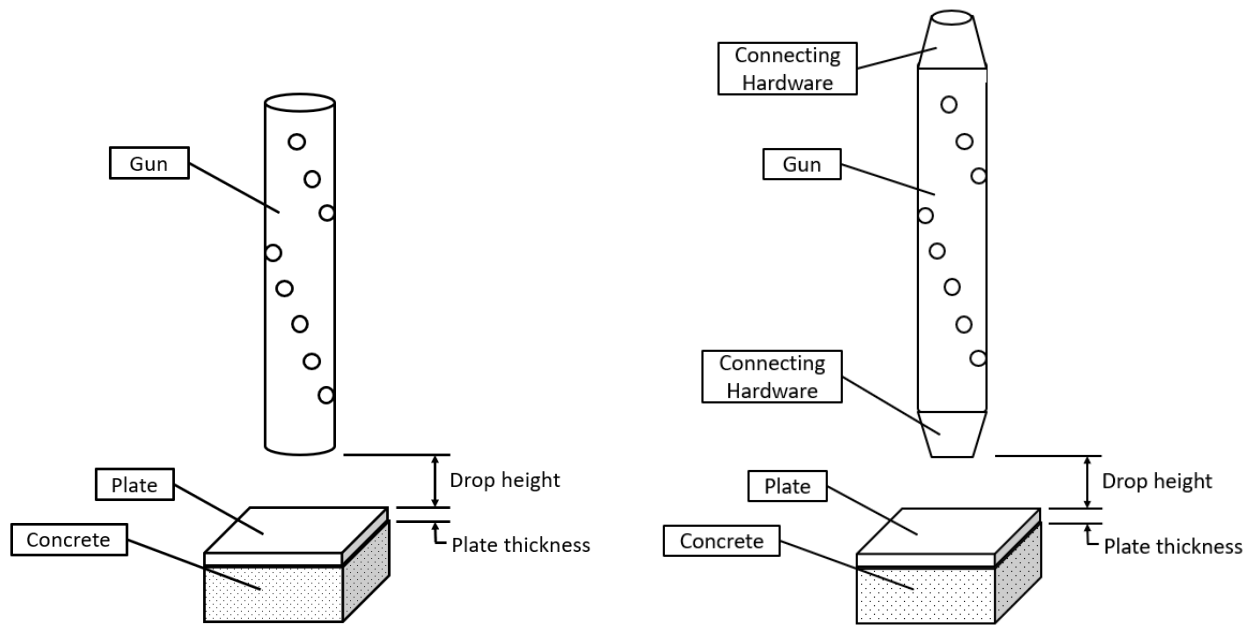


Figure C.1 - Drop Test Schematic

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 minimum level of evaluation as outlined in this document.

- Post drop, the system shall be opened by removing any end connection hardware that is attached to gun system.
- Measurements of the relative location of the internal end pieces shall be recorded pre and post drop.
- The relative location of the charges within the system shall be recorded pre and post drop.
- The condition of all explosive (or inert explosive) components shall be recorded.
- The condition of all structural or fastening components shall be recorded.

C.4.5 Drop Test Failure Criteria

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.

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.

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- [3] ASME B1.5, *Acme Screw Threads*
- [4] ISO 6506-1¹, *Metallic materials—Brinell hardness test—Part 1: Test method*
- [5] Machinery's Handbook
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