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Secretariat of ISO/TC 58/SC 3
Gas cylinders — Cylinder design

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Dear Member

ISO/CD 19881
pre-ballot draft

Please find attached a pre-ballot draft of ISO 19881, *Gaseous Hydrogen – Land Vehicle Fuel Tanks* currently being developed by ISO/TC 197/WG 18 *Gaseous hydrogen land vehicle fuel tanks and TPRDs.*

This is circulated for information only.

Yours sincerely

S W Read
Secretary to ISO/TC 58/SC 3

ISO/TC 197/WG 18
Gaseous hydrogen land vehicle fuel tanks and TPRDs

Email of secretary:
Convenorship: SCC (Canada)

Pre-Ballot Draft of ISO CD 19881 - 2015Jul21

Document type:	Committee draft
Date of document:	2015-07-24
Expected action:	INFO
Background:	Dear Colleagues, The ISO/WD 19881 document is currently being formatted into the appropriate CD template for balloting and comments. The vote/comment period will take 60 days, so this should conclude prior to our scheduled Oct.8-9 meeting. For your convenience, attached is the pre-ballot document in the old WD format. Please feel free to begin formulating your comments for submission to your respective member bodies once the CD is circulated for voting. As always, please feel free to contact me if you have any questions. Best regards, Livio
Committee URL:	http://isotc.iso.org/livelink/livelink/open/tc197wg18

COMMITTEE DRAFT

COMMITTEE DRAFT ISO/CD 19881	
Date 2015-07-21	Reference number **ISO/TC** 197 **/SC** **N**
Supersedes document	

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ISO/TC 197**/SC** Title Hydrogen Technologies Secretariat Standards Council of Canada (SCC)	Circulated to P- and O-members, and to technical committees and organizations in liaison for: ☐ information ☐ discussion at [venue/date of meeting] ☐ comments by [date] ☐ approval for registration as a CD in accordance with ____2.4.8 part 1 of the ISO/IEC Directives, by [date]

Title (English)

Compressed hydrogen gas vehicle fuel containers

Title (French)

Des réservoirs de carburant des véhicules au gaz d'hydrogène comprimé

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Foreword

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The committee responsible for this document is ISO/TC 197.

Contents

Compressed hydrogen gas vehicle fuel containers ISO/CD 19881

1 Scope

1.1 General

This International Standard contains requirements for the material, design, manufacture, marking, and testing of serially produced, refillable containers intended only for the storage of compressed hydrogen gas for vehicle operation. These containers:

a) are to be permanently attached to the vehicle;
b) have a capacity of up to 1 000 liters water capacity; and
c) have a nominal working pressure that does not exceed 70 MPa.

1.2 Alternative construction or materials

The construction of the containers, whether specifically covered by the various provisions of this Standard or not, is to be in accordance with reasonable concepts of safety, performance, and durability.

All specifications as to construction set forth herein are to be satisfied by the construction actually prescribed or such other construction as will provide at least equivalent performance.

1.3 Units of measurement

This International Standard contains SI (metric) units. IEEE/ASTM SI 10, or ISO 80000-1:2009, is used as a guide in making metric conversion from yard/pound quantities. If a value for measurement and a corresponding value in other units are stated, the first stated value is to be regarded as the requirement. The given corresponding value may be approximate. If a value for a measurement and a corresponding value in other units are both specified as a quoted marking requirement, the first stated unit, or both are to be provided.

1.4 Terminology

In this International Standard, “shall” is used to express a requirement, i.e. a provision that the user shall satisfy in order to comply with the standard; “should” is used to express a recommendation or that which is advised but not required; and “may” is used to express an option or that which is permissible within the limits of the standard.

Notes accompanying clauses do not include requirements or alternative requirements; the purpose of a note accompanying a clause is to separate from the text explanatory or informative material.

Notes to tables and figures are considered part of the table or figure and may be written as requirements.

Annexes are designated normative (mandatory) or informative (non-mandatory) to define their application.

2 Reference publications

This International Standard refers to the following publications, and where such reference is made, it shall be to the edition listed below, including all amendments published thereto.

CSA Group

B51-09
Boiler, Pressure Vessel, and Pressure Piping Code

ANSI/CSA HPRD 1-2013
Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers

ASQ (American Society for Quality Control)
ANSI/ISO/ASQ Q9000-2005
Quality management systems – Fundamentals and vocabulary

ASTM International
D638-10
Standard Test Method for Tensile Properties of Plastics

D2344/D2344M-00 (R2006)
Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates

D3359-09e2
Standard Test Methods for Measuring Adhesion by Tape Test

D3418-12e1
Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry

D4138-07a
Standard Practices for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive, Cross Sectioning Means

D4814-11b
Standard Specification for Automotive Spark-Ignition Engine Fuel

D7091-12
Standard Practice for Nondestructive Measurement of Fry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals

E8/E8M-11
Standard Test Methods for Tension Testing of Metallic Materials

E23-07ae1
Standard Test Methods for Notched Bar Impact Testing of Metallic Materials

E399-09e2
Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness K_{Ic} of Metallic Materials

E647-11e1
Standard Test Method for Measurement of Fatigue Crack Growth Rates

G154-12
Standard Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Nonmetallic Materials

BSI (British Standards Institute)
BS 7910:2005
Guide on Methods for Assessing the Acceptability of Flaws in Metallic Structures

CGA (Compressed Gas Association)
C-1-2009
Methods for Pressure Testing Compressed Gas Cylinders

C-6.4-2012
Methods for External Visual Inspection of Natural Gas Vehicle (NGV) and Hydrogen Gas Vehicle (HGV) Fuel Containers and Their Installations

IEC (International Electrochemical Commission)
62282-4-101
Fuel cell power systems for propulsion other than road vehicles and auxiliary power units – Fuel cell power systems for

industrial electrically driven forklift trucks - Safety

ISO (International Organization for Standardization)
148-1:2009
Metallic materials – Charpy pendulum impact test – Part 1: Test method

306:2004
Plastics – Thermoplastic Materials – Determination of Vicat Softening Temperature (VST)

7866:2012
Gas cylinders – Refillable seamless aluminium alloy gas cylinders – Design, construction and testing

9001:2008
Quality Management Systems – Requirements

9809-1:2010
Gas cylinders – Refillable seamless steel gas cylinders – Design, construction and testing – Part 1: Quenched and tempered steel cylinders with tensile strength less than 1 100 MPa

9809-2:2010

Gas cylinders – Refillable seamless steel gas cylinders – Design, construction and testing – Part 2: Quenched and tempered steel cylinders with tensile strength greater than or equal to 1 100 MPa

12108:2012

Metallic Materials – Fatigue testing – Fatigue crack growth method

14687-2:2008

Hydrogen Fuel – Product Specification – Part 2: Proton exchange membrane (PEM) fuel cell applications for road vehicles

19078:2013

Gas cylinders – Inspection of the cylinder installation, and requalification of high pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles

80000-1:2009

Quantities and units – Part 1: General

SAE International

J2578:2009

Recommended Practice for General Fuel Cell Vehicle Safety

J2579:2013

Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles

J2601:2010

Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles

J2719:2011

Hydrogen Fuel Quality for Fuel Cell Vehicles

J2760:2011

Pressure Terminology Used in Fuel Cells and Other Hydrogen Vehicle Applications

Sandia National Laboratory

Technical Reference for Hydrogen Compatibility of Materials (2008)

3 Definitions

The following definitions shall apply in this International Standard:

Accredited registrar — a qualified organization accredited by a national or international body (e.g. the Registrar Accreditation Board in the U.S. [RAB]) as operating a certification system (e.g. in accordance with BS EN 45012:1998, *Conformity Assessment Requirements for Bodies Providing Audit and Certification Management Systems,* that provides third-party assessment, certification, and registration of suppliers' quality systems to applicable standards (e.g. the ANSI/ASQ Q9000 Series, Q9000 Series, *Quality Management Systems: Fundamentals and Vocabulary*). The registrar's scope of accreditation is described by the accrediting body for particular industry sectors (e.g. Standard Industrial Classification [SIC]). The registrar is thereby authorized to issue accredited certificates of registration to suppliers in the recognized industry.

Autofrettage — a pressure application procedure, used in manufacturing composite containers with metal liners, which strains the liner past its yield point sufficiently to cause permanent plastic deformation that results in the liner having residual compressive stresses and the fibers having residual tensile stresses at zero internal pressure.

Burst pressure — the highest pressure reached in a container during a burst test.

Composite — a filament and resin system.

Container category — a unique class of containers that are intended for a specific usage:
Category A containers are containers that are intended to be used in light duty and heavy duty land vehicle applications, regardless of the potential for further qualification to the UN GTR for fuel cell vehicles.

Category B containers are containers that are intended to be further qualified in accordance with the UN GTR for fuel cell vehicles with a gross vehicle mass of 4 536 kg or less.

Category C containers are containers that are intended to be used on hydrogen powered industrial trucks.

Container type — container types are designated as follows:

a) Type 1 — Metal;
b) Type 2 — Resin impregnated continuous filament with metal liner with a minimum burst pressure of 125 percent of nominal working pressure. This container is hoop-wrapped;
c) Type 3 — Resin impregnated continuous filament with metal liner. This container is full-wrapped; and
d) Type 4 **—** Resin impregnated continuous filament with a non-metallic liner.

Design family – A group of containers consisting of one fully qualified design and variations on that design that comply with Table 5.

Destroyed — physically made permanently unusable.

Fold — the place where two material flows meet in such a manner as to create a sharp, visual groove.

Full-wrapped — the reinforcement by a composite material applied over the entire liner including the domes.

Hoop-wrapped — reinforcement by a composite material applied in a substantially circumferential pattern over the cylindrical portion of the liner so that the filament does not transmit any significant stresses in a direction parallel to the container longitudinal axis.

Leakage — release of contents through a defect or crack.

Liner — inner gas tight container or gas container to which the overwrap is applied.

Maximum fuelling pressure (MFP) — the maximum pressure applied to a compressed system during fuelling. The maximum fuelling pressure is 125 percent of the nominal working pressure.

Maximum service temperature — the maximum temperature to which the container will be subjected in normal service.

Minimum required burst pressure — the minimum burst pressure that is to be met during a burst test. This is the pressure needed to demonstrate the required stress ratio.

Nominal working pressure — the container pressure, as specified by the manufacturer, at a uniform gas temperature of 15°C and full gas content.

Operating pressure — the varying pressure that is developed in a container during service.

Permeation — diffusion of the gaseous contents to atmosphere at a molecular level, by means of pores or molecular gaps.

Pressures — all pressures are gauge pressures unless otherwise specified.

Autofrettage pressure — the pressure to which a container is taken with the intent of yielding the liner or inner surface of the container. The autofrettage operation is considered to be part of the manufacturing operation and is conducted prior to proof testing.

Fill pressure — the pressure attained at the actual time of filling. Fill pressure varies according to the gas temperature in the container, which is dependent on the filling parameters and the ambient conditions. The maximum fill pressure should not exceed 125 percent of nominal working pressure.

Hydrostatic pressure — the pressure to which a container is taken during acceptance testing (see Clause 18.3.5).

Pressure relief device (PRD) — a device that, when activated under specified performance conditions, is used to vent the container contents.

Pre-stressing — the process that puts the liner in compression. This can be done by autofrettage.

Rejectable damage — damage as outlined in ISO 19078 or CGA C-6.4 and in agreement with the manufacturer's recommendations.

Rupture — sudden and unstable damage propagation in the structural components of the container resulting in loss of contents (see Leakage).

Settled pressure — the gas pressure when a given settled temperature is reached.

Settled temperature — the uniform gas temperature after any change in temperature caused by filling has dissipated.

Stress ratio — the minimum ultimate strength of the fiber, as determined in pressure container burst tests, divided by the stress in the fiber at nominal working pressure.

4 Service conditions

4.1 General

4.1.1 Standard service conditions

The standard service conditions specified in this clause are provided as a basis for the design, manufacture, inspection, testing, and approval of containers that are to be mounted permanently on vehicles and used to store compressed hydrogen for use as a fuel on-board the vehicles. Containers are intended to be installed on vehicles in accordance with SAE J2578, SAE J2579, IEC 62282-4-101, or other equivalent regulations and standards.

Note: *The manufacturer of the container is responsible for certifying that the container meets all applicable government regulations.*

4.1.2 Category

Category A containers are intended to be used in light duty and heavy duty land vehicle applications, regardless of the potential for further qualification to the UN GTR for fuel cell vehicles.

Category B containers are Type 4 designs of 70 MPa nominal working pressure and are intended to be further qualified in accordance with the UN GTR for fuel cell vehicles with a gross vehicle mass of 4 536 kg or less.

Category C containers are containers that are intended to be used on hydrogen powered industrial trucks.

Category A and Category B containers are intended to provide a sufficient level of safety for the intended application, but type, test methods, and records are different to facilitate regulatory compliance.

4.1.3 Service life

The service life for the containers shall be specified by the manufacturer. The specified life shall not be less than 10 years or greater than 25 years as defined in Clause 4.3.

4.1.4 Periodic in-service inspections

Any requirements and procedures for periodic re-qualification by inspection or testing during the service life shall be specified by the container or vehicle manufacturer on the basis of use under the service conditions specified herein. For containers that require periodic re-qualification by inspection or testing, the container label shall identify this requirement per Clause 16. Guidance on periodic inspection is included in informative Annex A of this Standard.

4.2 Pressures

4.2.1 Nominal working pressures

This International Standard applies to containers that have a nominal working pressure, as specified by the container manufacturer, of 25MPa, 35MPa, 50MPa, or 70MPa at 15°C, hereinafter referred to in this International Standard as the following:

a) “H25” — 25 MPa;
b) “H35” — 35 MPa;
c) “H50” — 50 MPa; or
d) “H70” — 70 MPa.

Note: *Other nominal working pressures for hydrogen gas besides those defined are allowed if the required qualification test requirements of this specification are met.*

4.2.2 Maximum pressures

Containers are designed to be filled to a pressure not exceeding any of the following conditions:

a) A pressure that would settle to the nominal working pressure at a settled temperature of 15°C.
The fill pressure shall be temperature compensated to prevent pressures from exceeding the maximum pressures that are defined.

b) 125 percent of the nominal working pressure immediately after filling, regardless of temperature.

4.3 Maximum number of filling cycles

Containers are designed to be filled to pressures not exceeding the requirements of Clause 4.2.2, as follows:

a) **Category A:**
For a maximum of 750 times the service life of the container in years for a minimum of 10 years and a maximum of 25 years.

b) **Category B:**
For a maximum of 5 500, 7 500, or 11 000 for a 15 year service life.

c) **Category C:**
For a maximum of 1 125 times the service life of the container in years for a minimum of 10 years and a maximum of 25 years.

Note: *Containers are expected to be removed from service when the service life used in the design qualification has expired, consistent with the labeling requirements in Clause 16.*

4.4 Temperature range

4.4.1 Settled gas temperatures

Settled temperature of gas in containers may vary from a low of −40°C to a high of 85°C.

4.4.2 Container temperatures

The temperature of the container materials may vary from −40°C to 85°C.

4.4.3 Transient gas temperatures

Transient gas temperatures (temperatures that would be insufficient to change the bulk temperature of the liner material) during filling and discharge may vary beyond the limits described in Clause 4.4.1. Containers qualified to meet this Standard shall be capable of being filled safely utilizing SAE J2601 fueling protocol or an equivalent fueling protocol.

4.4.4 Test temperatures

Unless otherwise specified, all tests shall be conducted at an ambient temperature of 20 ± 5°C.

4.5 Gas composition

Containers made to this International Standard are designed to be used with hydrogen fuel complying with ISO 14687-2, or SAE J2719.

4.6 External surfaces

Container external surfaces shall be designed to be resistant to environmental conditions outlined in Clause 18.3.3.

4.7 Installation requirements

The container manufacturer shall provide information to the vehicle manufacturer or system integrator as necessary to support proper installation in the vehicle.

The vehicle manufacturer or system integrator shall be responsible for the protection of the container, container valves, pressure relief devices, and connections as required by applicable regulations per the authority having jurisdiction (AHJ). Standards that apply to this requirement include SAE J2578, SAE J2579, IEC 62282-4-101, or other equivalent standards.

If this protection is mounted to the container, the design and method of attachment shall be approved by the container manufacturer. Factors to be considered include the ability of the container to support the transferred impact loads and the effect of local stiffening on container stresses and fatigue life.

Containers shall be protected from accidental cargo spillage and from mechanical damage. This International Standard contains no requirements for container integrity in a vehicle collision. Container locations and mountings should be designed to provide adequate impact protection to prevent container failure in a collision.

5 Compliance

Compliance shall be required in all details, without exception. If there is evidence of a fault in carrying out a test or an error in measurement, another test shall be performed. If the results of this test are satisfactory, the results of the prior test shall not be a basis for rejection.

6 Material qualification tests and requirements

6.1 General

All structural materials shall be traceable to their original manufacturer's certified test reports. The materials shall be of uniform quality. Materials not in compliance with the manufacturer's design specifications are not authorized.

Table 1 summarizes specific materials tests that are required in this Clause 6 and subsequent Clauses.

Table 1
Material Tests

			Container Type			
Material tests	**Clause**	**Material type**	**1**	**2**	**3**	**4**
Impact test	6.3.2	Steel	•	•	•	•
Tensile test	6.3.3	Metals	•	•	•	•
Sustained load cracking test	6.3.4	Aluminum	•	•	•	•
Corrosion test	6.3.5	Aluminum	•	•	•	•
Ultraviolet resistance test	6.4	External coatings	•	•	•	•
Shear strength test	6.6	Resins		•	•	•
Glass transition temperature test	6.6	Resins		•	•	•
Tensile test	6.7	Nonmetallic liners				•
Softening temperature test	6.7	Nonmetallic liners				•
Tensile test	10.3	Nonmetallic liner welds				•

6.2 Material requirements

Materials normally in contact with hydrogen shall be determined to be acceptable in hydrogen service, with consideration of hydrogen embrittlement and hydrogen accelerated fatigue. The performance tests cannot guarantee that all cases and conditions of hydrogen service will be validated, so it is still incumbent on the manufacturer to carefully screen materials of construction for their intended use. Materials and design shall be such that there will be no significant change in the functioning of the container, deformation or mechanical change in the container, and no harmful corrosion, deformation, or deterioration of the materials when subject to the service conditions provided in Clause 4.

Note: *Material performance data in hydrogen environments can be found in the Sandia National Laboratory Technical Reference for Hydrogen Compatibility of Materials or ANSI/AIAA G-095, ANSI/CSA CHMC 1, ASME B31.12, and SAE J2579, Appendix B, or in equivalent national requirements.*

Nonmetallic materials normally in contact with hydrogen shall be determined to be acceptable in hydrogen service. Consideration shall be given to the fact that hydrogen diffuses through these materials more easily than through metals; therefore, the suitability of materials shall be verified. Nonmetallic materials shall retain their mechanical stability with respect to strength (fatigue properties, endurance limit, creep strength) when exposed to the full range of service conditions and lifetime as specified by the manufacturer. Materials shall be sufficiently resistant to the chemical and physical action of the fluids that they contain and to environmental degradation. The chemical and physical properties necessary for operational safety shall not be significantly affected within the scheduled lifetime of the equipment unless replacement is foreseen; specifically, when selecting materials and manufacturing methods, due account shall be taken of the material's corrosion and wear resistance, electrical conductivity, impact strength, aging resistance, the effects of temperature variations, the effects arising when materials are put together (for example, galvanic corrosion), the effects of ultraviolet radiation, and the degradation effects of hydrogen on the mechanical performance of a material.

6.3 Metal containers and metal liners

6.3.1 Material properties

Steels shall be aluminum killed and produced to predominantly fine grain practice. Steels shall have a maximum tensile strength of 950 MPa for chrome-molybdenum steel and 880 MPa for carbon-manganese steels. For all other steels, the manufacturer shall demonstrate that exposure to high-pressure hydrogen under the service conditions provided in Clause 4 will not cause any harmful corrosion, deformation, or deterioration of the material. The chemical composition of all steels shall be declared and defined at least by:

a) carbon, manganese, aluminum, and silicon contents in all cases; and
b) nickel, chromium, molybdenum, boron, vanadium, or any other elements that are deliberately added.

The following limits shall not be exceeded in the cast analysis:

	950 MPa or less
Sulfur	0.020%
Phosphorus	0.020%
Sulfur and Phosphorus	0.030%

Aluminum alloys shall be quoted in line with Aluminum Association practice for a given alloy system. The impurity limits for lead and bismuth in any aluminum alloy shall not exceed 0.010 percent. Excess silicon 6xxx series aluminum alloys with yield strengths above 250 MPa (e.g. 6351 and 6082) shall not be used in fuel containers or liners.

6.3.2 Impact test for steel

The impact properties of the steel in the finished container or liner shall be determined in general accordance with ISO 148-1, or ASTM E23. The impact test pieces shall be taken from the wall of the container in the transverse direction. The notch plane orientation shall be in the C-L direction (i.e., perpendicular to the circumference and along the length). Test pieces with a width of less than 5 mm shall be taken from the longitudinal direction. If the wall thickness does not permit a final test piece width of 10 mm, the width shall be as near as practicable to the nominal thickness of the container wall. All impact tests shall be conducted at −40°C. Impact values shall not be less than that indicated as follows:

Width of test piece	(mm)	5.0 - 7.5	7.5 - 10.0
Impact Strength	(J/cm^2)	44	50

a) Impact values for test pieces of width less than 5 mm shall be based on special studies of particular materials and particular specimens.
b) Required average results of three specimens.
c) Not more than one specimen shall break at less than the average value required and no single specimen shall break at less than 80 percent of the average value.

6.3.3 Tensile tests for metals

Tensile strength methods shall be as prescribed by Test Methods of ASTM E8M, and shall meet the requirements of the designs. Alternatively, tensile tests shall be carried out in accordance with ISO 9809-1 for steels, and ISO 7866 for aluminum.

6.3.4 Sustained load cracking (SLC) test for aluminum

The resistance to SLC shall be determined in accordance with Annex B of ISO 7866, and shall meet the requirements therein.

6.3.5 Corrosion tests for aluminum

Corrosion tests for aluminum alloys shall be carried out in accordance with Annex A of ISO 7866, and shall meet the requirements therein.

6.4 Ultraviolet resistance of external coatings

Protective coatings required to meet Clause 18.3.2 shall be evaluated for resistance to ultraviolet effects using a minimum 1 000 hours exposure using a UVA 340 lamp in accordance with the current edition of ASTM G154. Evidence of blistering, cracking, chalking, or softening shall be cause for rejection.

6.5 Fibers

Structural reinforcing filament material types shall be glass fiber, aramid fiber, or carbon fiber. If carbon fiber reinforcement is used, the design shall incorporate means to prevent galvanic corrosion of metallic components of the fuel container.

6.6 Resins

The material for impregnation may be thermosetting or thermoplastic resin. Examples of suitable matrix materials are epoxy, modified epoxy, polyester and vinylester thermosetting plastics, and polyethylene and polyamide thermoplastic material. Resin system materials shall be tested on a sample test panel, representative of the composite overwrap, in accordance with ASTM D2344. Following a 24-hour water boil, the composite shall have a minimum shear strength of 13.8 MPa.

Resin system materials shall have a glass transition temperature of at least 20°C above the maximum container temperature (i.e ≥105°C). The glass transition temperature of resin materials shall be determined in accordance with ASTM D3418.

6.7 Nonmetallic liners (Type 4)

The nonmetallic liner material shall be compatible with the service conditions specified in Clause 4.

The liner melt temperature shall be sufficiently high to allow gas release only through pressure relief devices during fire tests. See Clause 18.3.8 for further details.

The tensile yield strength and ultimate elongation shall be determined in accordance with ASTM D638. Tensile or impact testing shall be conducted on samples of the nonmetallic liner material to demonstrate that the material fails in a ductile, rather than brittle, mode at temperatures down to and including −50°C.

The softening temperature shall be sufficiently high to meet the service conditions specified in Clause 4. The manufacturer shall establish the suitable value for softening temperature and testing shall be in accordance with the method described in ISO 306, or using an equivalent method.

6.8 Bosses for Type 4 containers

Materials shall be compatible with the liner and intended environment and shall meet the requirements of Clauses 6.2, 6.3.1 (with the exception that the lead and bismuth restriction does not apply), 6.3.2, 6.3.3, 6.3.4, and 6.3.5 as applicable.

7 Wall thickness

7.1 Type 1 containers

The minimum wall thickness shall be sufficient to comply with all applicable qualification tests within this Standard.

7.2 Liners for Type 2, Type 3, and Type 4 containers

Minimum thickness of the liner shall be such that the required qualification test requirements of this Standard are met.

For Type 2 designs, the unreinforced metal liner shall have a minimum burst pressure of 125 percent of nominal working pressure.

7.3 Composite reinforcement for Type 2, Type 3, and Type 4 containers

7.3.1 Stress analysis

The stress analysis is applicable to Category A and C containers only.

Stresses in the liner and composite reinforcement shall be computed using suitable analysis techniques that have been demonstrated to adequately predict the stresses and strains in both the liner and the composite overwrap at the following pressures: autofrettage (Type 2 and 3 only), pressure, zero gauge pressure (after autofrettage for Type 2 and Type 3), nominal working pressure, hydrostatic test pressure, and minimum burst pressure.

7.3.2 Stress ratios

The composite overwrap shall be designed for high reliability under sustained loading and cyclic loading. This reliability shall be achieved by meeting or exceeding the following composite reinforcement stress ratio values shown below:

Material	Type 2	Type 3	Type 4
E-Glass	2.65	3.5	3.5
S-Glass	2.65	3.5	3.5
Aramid	2.25	3.0	3.0
Carbon	2.25	2.25	2.25

7.3.3 Modified stress ratio test

At the option of the manufacturer, or for designs in which the required minimum container burst pressure is not sufficient to cause tensile failure in the fiber, a modified burst test procedure may be used to verify that the fiber stress ratio at nominal working pressure is achieved. The stress ratio requirements (2.65) for E-glass and S-glass, reinforced Type 2 containers, may be demonstrated by meeting a minimum hold time at a specified pressure during the burst tests conducted under Clause 13.5 or 18.3.5. Acceptable alternative combinations of hold times and pressures are as follows:

a) 1 minute at 250 percent of nominal working pressure; or
b) 1 hour at 225 percent of nominal working pressure.

As an alternative, the strength of the fiber may be verified by the testing of containers, with the composite thickness reduced by no more than 50 percent, to cause failure initiation in the composite.

7.3.4 Hybrid designs

Hybrid construction (using more than one type of reinforcing fiber) shall be permitted. The strength of the individual types of fibers used in hybrid construction may be verified by testing of containers reinforced with a single type of fiber. In a hybrid construction, the applicable stress ratio requirements shall be met in one of the two following ways:

a) if load sharing between the various fiber reinforcing materials is considered a fundamental part of the design, each fiber shall meet the stated stress ratio requirements; or

b) if load sharing between fibers is not considered as a fundamental part of the design, then one of the reinforcing fibers shall be capable of meeting the stress ratio requirements even if all other fiber reinforcing materials are removed.

7.4 External loads on containers

Containers with greater than 450 liters water capacity and all containers employing integral mounts or valve protection shall consider the external loads imposed on the container as a function of the service conditions and mounting provisions. This would include bending and torsional stresses.

8 Threaded openings

Threads shall be clean cut, even, and to gauge.

All threads shall comply with a recognized international or national standard.

Tapered threads are only permitted on steel containers, steel liners, and steel bosses.

9 Inspection requirements

9.1 Inspection during qualification

All design qualification tests shall be conducted or witnessed by an independent inspection or test agency that is nationally recognized.

The nationally recognized testing agency shall be accredited.

9.2 Inspection during manufacturing

If the manufacturer's quality system is approved in accordance with Clause 17.1, Option 1, the manufacturer may perform all inspections and verifications during manufacturing, subject to monitoring by the accredited registrar.

If the manufacturer's quality system is in accordance with Clause 17.1, Option 2, and Clause 17.2, all inspections and verifications during manufacturing shall be performed by a representative of a qualified independent inspection agency. The independent inspection agency shall comply with the requirements of Clause 17.2(a).

9.3 Duties of inspector during manufacturing

9.3.1 Duties performed by all manufacturing inspectors

The following duties apply during manufacture to the inspectors engaged by a manufacturer with an approved quality system in accordance with Clause 17.1, Option 1, or to third party inspectors engaged by manufacturers operating quality systems in accordance with Clause 17.1, Option 2, and Clause 17.2:

a) Verify proper identification and compliance of all materials with the requirements specified in Clause 6. Chemical analysis of metals may be verified by obtaining the producer's certified analysis.

b) Verify compliance with manufacturing design specifications on the interior and exterior surfaces of liners and completed containers.

c) Verify winding process of Types 2, 3, and 4 containers to determine that the composite material is of required thickness and wrap pattern and in accordance with the composite structure present in containers subjected to the design qualification tests.

d) Verify compliance of threads, by gauge.

e) Verify proper thermal treatment of materials.

f) Verify that each container has been hydrostatically tested and the data recorded as specified by the manufacturer.

g) Select all test samples, witness all tests, and obtain copies of all test results and certifications.

h) Verify compliance of each container with all requirements, including marking.

i) Prior to the initial in service usage of any container of a new design, or with a design change, verify that the applicable design qualification tests specified in Clause 18 have been performed with acceptable results.

j) Furnish complete inspector's record in accordance with Clause 15 to the manufacturer of the container.

9.3.2 Additional duties (to Clause 9.3.1) performed by third party inspectors

The following duties apply to third party inspectors engaged by manufacturers operating quality systems in accordance with Clause 17.1, Option 2, and 17.2. These items shall be audited at least every 12 months:

Note: For manufacturers with approved quality systems in accordance with Clause 17.1, Option 1, the following duties and periodic audits are already required as part of certification of the quality system.

a) Verify that the manufacturer's quality manual addresses design, purchasing, process control, inspection, test, and configuration management, and that the quality manual and practices of the manufacturer are consistent with one another.

b) Verify that product drawings adequately define the configuration to be manufactured and that containers meet the drawing requirements.

c) Verify that design documents contain appropriate acceptance criteria.

d) Verify that purchased parts are inspected for conformance to specified requirements.

e) Verify that adequate written instructions are provided for manufacture of containers that are in conformance with specified requirements.

f) Verify that incoming product and material have been inspected or otherwise verified as conforming to specified requirements.

g) Verify that no product is shipped until all specified inspections and tests are completed and the containers are found to be compliant with specifications.

h) Verify that procedures for non-conforming material control are being followed.

i) Verify that inspection and test equipment are properly calibrated.

j) Verify that records are kept that give evidence that the product has passed inspection and test requirements with defined acceptance criteria.

k) Verify that procedures are followed that control documents and data related to the manufacturer of containers. These procedures apply to both initial document release and to revisions.

9.4 Inspection during service

Guidance on periodic in-service inspection is included in informative Annex A of this Standard.

10 Manufacture

10.1 General

Manufacturing processes shall be the same as those used to produce the containers subjected to design qualification tests and shall be specified by the manufacturer in sufficient detail to produce consistent product. No defect shall be acceptable that is likely to cause failure within the lifetime of the container.

10.2 Metal containers and metal liners

Surfaces shall have dirt and scale removed, as necessary, to afford proper inspection. A reasonably smooth and uniform surface finish shall be required. No interior folding shall be permitted. Smooth gathering of the material, in the neck or dome area in which there are no sharp rooted folds, shall be acceptable. If not originally free from such defects, the liner or container surface may be machined or otherwise treated to eliminate these defects provided the required minimum wall thickness is maintained. The liner or container end contour shall be concave to pressure.

10.3 Nonmetallic liners

Nonmetallic liners shall be free of contaminants as necessary to afford proper inspection. Interior folds, laps, or sharp surface indentations are not permitted. If not originally free from such defects, the liner surface may be reworked to eliminate these defects providing the liner then meets all design requirements. Welded construction of non-metallic liners shall be permissible.

Liner weld processes, particularly time, temperature, and joining force, shall be monitored during the welding process and controlled within the parameters established by the manufacturer. Tensile tests of liner weld specimens shall be conducted on samples manufactured at the extreme limits of the process within which the manufacturer will control the weld process.

Tensile testing of liner weld specimens shall be conducted during qualification of the weld process at −50°C or colder at ambient temperature, and at 85°C or hotter.

Tensile specimens shall fail either outside the weld joint or with a ductile failure, if the failure is within the weld.

10.4 Composite containers with metallic liners

The container shall be fabricated from a metal liner overwrapped with resin impregnated continuous filament windings. The winding pattern shall be in the "hoop" direction for "hoop-wrapped" containers or in the "helical or in-plane" and "hoop" directions for "full-wrapped" containers. The windings shall be applied under controlled tension to develop the design composite thickness. After the winding is complete, composites using thermoset resins shall be cured by a controlled temperature process that does not compromise the performance of the liner.

10.5 Composite containers with nonmetallic liners

Type 4 composite containers shall be fabricated from a nonmetallic liner overwrapped with resin impregnated continuous filament windings. The winding shall be applied under controlled tension to develop the design composite thickness. After the winding is complete, composites using thermoset resins shall be cured by a controlled process that does not compromise the performance of the liner.

Composite containers with nonmetallic liners shall be designed such that if, when pressurized, the liner is susceptible to creep and flow, no leakage will occur during the prescribed lifetime.

Note: *The softening temperature for the liner is permitted to be exceeded during processing if the qualification testing verifies that the completed container passes all required tests.*

10.6 Brazing

Brazing for any purpose whatsoever shall not be permitted.

10.7 Welding

Welded construction of metal containers, liners, and bosses shall not be permitted.

10.8 End closing by forming

The ends of aluminum containers or liners shall not be closed by a forming process. The base ends of steel containers or liners which have been closed by forming, except those containers or liners designed in accordance with ISO 9809-1 shall be NDE Inspected. Metal shall not be added in the process of closure at the end. Each container or liner shall be examined before end forming operations for thickness and surface finish.

10.9 Mounting and protection

If mounting provisions and/or valve protecting shrouds are required, they shall be permitted to be manufactured as part of the container, providing they are not detrimental to the performance of the container. If manufactured as part of the container, structural integrity shall be demonstrated by compliance with qualification tests specified in Table 2 or Table 3, as applicable.

10.10 Batch definitions

10.10.1

The batch definitions shall be as follows:

a) Metal liners and containers only. A "batch" shall be a group of metal liners or containers successively produced having the same design, specified material of construction, process of manufacture, process of heat treatment, equipment of manufacture, equipment of heat treatment, and conditions of time, temperature, and atmosphere during heat treatment as the batch acceptance sample, with the only variation being length up to ± 50 percent.

b) Nonmetal liners only. A “batch” shall be a group of nonmetal liners successively produced having the same design, specified material of construction, process of manufacture, and equipment of manufacture as the batch acceptance sample, with the only variation being length up to ± 50 percent.

c) Composite container only. A “batch” shall be a group of containers successively produced from liners having the same design, specified materials of construction, process of manufacture, and autofrettage process as the batch acceptance sample, with the only variation, applicable to Type 2 containers only, being length up to ± 50 percent.

10.10.2

In no case shall a “batch” be permitted to exceed 200 units plus destructive test units, or one shift of production, whichever is greater.

10.11 Design qualification tests

Prior to initial in service usage of any specific container design, qualification tests as prescribed in Clause 18, shall be performed with satisfactory results.

11 Production tests and examinations

11.1 General

Production examinations and tests shall be carried out by the following means on all containers produced in a batch:

a) verification through non-destructive examination that flaws in metal containers and liners do not exceed the manufacturer's specified limits;

Note: Guidance for determination of the manufacturer's specified limits can be found in Annex B of this Standard.

b) verification through visual or non-destructive examination that nonmetallic liners are free of flaws exceeding the manufacturer's specified limits (see Clause 10.3 for types of flaws);
c) verification that the critical dimensions and parameters specified by the manufacturer of the completed container and of any liner and overwrapping are within design tolerances. Statistical sampling of critical dimensions shall be acceptable provided that the process is demonstrated capable of maintaining a process capability index (Cpk) of 1.33 or more;
d) verification of compliance with specified surface finish with special attention to deep drawn surfaces and folds or laps in the neck or dome area of forged or spun end closures or openings;
e) verification of coating quality (if required);
f) verification of markings; and
g) verification of strength (heat treatment) of metal containers liners and bosses. For Type 1 containers and Type 2 liners, a hardness test or equivalent shall be required.

A summary of critical production inspection requirements to be performed on every container is provided in Table 2.

Any container not meeting the specifications in Table 2 shall be rejected. Prior to initial in service usage of any specific container design, qualification tests as prescribed in Clause 18, shall be performed with satisfactory results.

Table 2
Production verification requirements
(See Clause 11.1.)

			Container Type:

Production verification requirement(s):	Liners or finished containers	Provision	1	2	3	4
Dimensions		11.1 (c)	X	X	X	X
Flaws		11.1 (a) and (b)	X	X	X	X
Strength (heat treatment) of metal containers, metal liners, and metal bosses		11.1 (g)	X	X	X	X
Hydrostatic test		11.2	X	X	X	X
Leak test		11.3	*	*	*	X
Coatings (where required)		11.1(e)	X	X	X	X
Surface finish		11.1(d)	X	X	X	X
End closing by forming (Steel)		10.8	X	X	X	
Markings		11.1(f)	X	X	X	X

** Leak tests shall be conducted on those container types that are closed by forming.*

11.2 Hydrostatic test

Each finished container shall be hydrostatically tested to at least 150 percent of nominal working pressure. Measuring systems for pressure and expansion shall meet the accuracy and periodic calibration requirements of CGA Pamphlet C-1.

Pressure shall be maintained for 30 seconds and sufficiently longer to produce complete expansion. If the test pressure cannot be maintained due to failure of the test apparatus, it shall be permissible to repeat the test at a pressure increased by 690 kPa minimum.

The manufacturer shall define the appropriate limit of elastic and permanent volumetric expansion for the test pressure used. The manufacturer shall record all actual test results. Any containers not meeting the defined rejection limit shall be destroyed.

11.3 Leak test

All containers shall be leak-tested using the procedures in Items (a) and (b) or an acceptable alternative method. Containers with multiple sealing connections shall be leak-tested at each connection. Permeation through the wall in compliance with Clause 18.3.11 shall not be considered to be leakage.

a) Containers shall be thoroughly dried, then pressurized to nominal working pressure with a detectable gas or gas mixture.
b) Containers shall be placed in an enclosure to permit detection of any leaks.

Any gas detected beyond the allowable permeation rate shall be cause for rejection.

Note: *Extreme care should be taken not to create explosive mixtures of gases within the container or test area (enclosure) when using combustible gases.*

12 Batch tests

12.1 General

Batch testing shall be conducted on finished containers or liners that are representative of normal production and are complete with identification marks. The test containers, and liners, as appropriate, shall be randomly selected from each batch. If more containers are subjected to the tests than are required by this Standard, all results shall be documented.

When the test results fail to meet requirements, the container or liner batch shall be rejected. One retest of a rejected batch may be authorized if the test result identifies the presence of a defect in the container or liner and the batch is 100 percent inspected to remove defective containers or liners from the batch. A second sample shall then be permitted to be selected from the batch and tested. The batch shall be considered acceptable if the second sample meets the batch criteria.

12.2 Batch material tests

The container or liner shall meet the requirements of the design when subjected to the following tests:

a) Dimensions checked against the design.
b) For metal containers and liners, tensile test two specimens in accordance with the appropriate method specified under Clause 6.3.3.
c) For steel containers and liners, three impact tests in accordance with the method specified under Clause 6.3.2.

12.3 Coated containers

When a protective coating is a part of the design, the following tests shall be performed (in order) on a finished container or a representative test panel from each coating batch:

a) Coating thickness tests shall be in accordance with the following appropriate test method:
    i) ASTM D7091
    ii) ASTM D4138
b) Containers that do not meet the manufacturer's specified coating thickness requirement may be recoated after appropriate surface preparation without prior re-stripping.
c) The coating adhesion test in accordance with ASTM D3359 shall provide a minimum rating of 4 when measured using either test method A or B, as appropriate.

Repair of tested surfaces shall be permitted to a manufacturer's approved procedure.

Where the coating fails to meet the requirements, the batch shall be 100 percent inspected to remove similarly defective containers. The coating on all defective containers may be stripped, using a method that does not affect the integrity of composite wrapped containers, and re-coated. The coating batch test shall then be repeated.

12.4 Burst test

12.4.1 Batch burst test

One container selected from each batch shall be hydrostatically pressurized to burst in accordance with the test procedure described in Clause 18.3.5(a). Rupture may occur in any region of the container. The burst pressure shall meet or exceed the minimum required burst pressure; otherwise, the batch shall be rejected.

The container used for the cycle test in Clause 12.5 may be used for the burst test. If the burst pressure of the cycled container is less than the minimum required burst pressure, an additional burst test shall be conducted on another container selected from the batch. The burst pressure on the additional container shall meet or exceed the minimum required burst pressure; otherwise, the batch shall be rejected.

12.4.2 Periodic burst test

12.4.2.1

The requirement in Clause 12.4.1 to burst a container from each batch may be replaced by periodic burst testing. For the first five sequential batches of a design family (i.e., similar materials, processes, and stress levels, but allowing different sizes) one container from each batch shall be burst tested in accordance with the requirements of Clause 12.4.1. If the container from any batch fails to meet the minimum required burst pressure, the batch shall be rejected.

12.4.2.2

If five sequential batches pass the burst test, then subsequent burst tests are only required on every tenth batch manufactured. If more than three months have passed since the last batch of containers was burst-tested, then a container from the next batch of containers manufactured shall be burst tested.

12.4.2.3

If a container fails to meet the minimum burst test requirement, then the batch shall be rejected and a sample from every batch manufactured since the previous periodic burst test shall be tested. Any failure to meet the minimum burst test requirement shall also cause rejection of the corresponding batch. A representative container from each of the next ten batches shall be burst tested.

12.5 Cycle test

12.5.1 Batch cycle test

One container selected from each batch shall be pressure cycle tested in accordance with the following. Leakage may occur in any region of the container. The number of cycles attained before failure shall meet or exceed the number specified below; otherwise, the batch shall be rejected.

12.5.2 Periodic pressure cycling test

12.5.2.1

The container shall be pressure cycle tested in accordance with the following procedures:

a) fill the container to be tested with a non-corrosive fluid such as oil, inhibited water, or glycol; and

b) cycle the pressure in the container between 2 (±1) MPa to at least 125 percent of nominal working pressure for a total number of cycles equivalent to 750 times the service life of the container in years for Category A containers, or to 5 500, 7 500, or 11 000 cycles as appropriate for Category B containers, or to 1 125 times the service life of the container in years for Category C containers.

12.5.2.2

The first five sequential batches of a design family shall be tested to a total number of cycles equivalent to 750 times the service life of the container in years for Category A containers, or to 5 500, 7 500, or 11 000 cycles as appropriate for Category B containers, or to 1 125 times the service life of the container in years for Category C containers, not to exceed 10 cycles per minute. If the container from any batch fails to meet this requirement, the batch shall be rejected.

12.5.2.3

If five sequential batches pass the cycling test, then subsequent pressure cycling tests shall only be required on every tenth batch manufactured. If more than three months have passed since the last batch of containers was cycle tested, then a container from the next batch of containers manufactured shall be cycle tested.

12.5.2.4

If a container fails to meet the cycle requirement, then the batch shall be rejected and a representative container from each of the next 10 batches shall be cycle tested.

13 Rejected containers and liners

13.1 Physical test

Reheat treatment of metal containers or metal liners shall be authorized; subsequent thereto, acceptable containers or liners shall pass all prescribed tests. One additional heat treatment shall be allowed for aluminum and two additional heat treatments are allowed for steel. Additional heat treatments require validation by material properties testing (Clauses 6.3.2 and 6.3.3) for steels.

13.2 Leak test

Containers with leaks (see Clause 11.3) shall not be placed in service.

13.3 Hydrostatic test

Rejected containers (see Clause 11.2) shall not be placed in service.

13.4 Cycle test

Containers from rejected batches (see Clause 12.5) shall not be placed in service.

13.5 Burst test

Containers from rejected batches (see Clause 12.4) shall not be placed in service.

14 Pressure relief devices

Containers shall be protected from rupture in a fire situation. This protection shall be provided by a pressure relief device(s) complying with ISO 19882. The effectiveness of the pressure relief devices shall be demonstrated in accordance with Clause 18.3.8.

Note: *Installation standards may permit alternative configurations if they can be demonstrated to provide adequate levels of safety. A manufacturer may specify additional PRD locations for specific vehicle installations to optimize safety considerations.*

15 Records of manufacture

The manufacturer shall record appropriate information on the materials, manufacturing processes, and test results for the fuel containers. These records shall be clear, legible, and in general accordance with the forms in Annex B.

The inspector shall furnish completed test reports to the container manufacturer.

The inspector's record shall be retained by the container manufacturer and the inspector for a minimum of the service life of the container plus five years from the original test date on the containers.

16 Marking and dispatch

16.1 Markings

16.1.1 General

On each container, the manufacturer shall provide clear permanent markings. Markings may be included on either a single label or divided among multiple labels. Any labels should be located such that they are not obscured by mounting brackets. Duplicate labels are allowed.

16.1.2 Marking information

Each container complying with this International Standard shall be marked as follows:

a) Mandatory information:
b) Marking in accordance with government regulations, including at a minimum:
   i) name and contact information of the manufacturer;
   ii) date of manufacture;
   iii) date of removal from service; and
   iv) number of cycles used in the test program (Category B containers only);
c) ISO 19881:xxxx-Hyyz (where "xxxx" denotes the year of the standard to which the container is designed, "yy" denotes the nominal working pressure designation identified in Clause 4.2.1, and "z" denotes the A, B or C designation identified in Clause 4.3);
d) MFP xx.x (where "xx.x" denotes the maximum fuelling pressure);
e) Manufacturer's part number and serial number;
f) The statement "For Use Only With The Container Manufacturer's Approved Pressure Relief Devices and Valves."; and
g) The statement "Container Service Life Ends After Use in a Single Vehicle – Container Transfer Between Vehicles is Prohibited."
h) Non-mandatory information can be added but it shall be presented in such a form that it will not be confused with mandatory information. All non-mandatory information shall follow or be separate from the mandatory information sequence.

The markings shall be placed in the listed sequence but the specific arrangement may be varied to match the space available.

16.2 Dispatch

Prior to dispatch from the manufacturer's shop, every container shall be internally clean and dry and every container shall be inspected as required by the manufacturer. Containers not immediately closed by the fitting of a valve, and safety devices if applicable, shall be closed using a method that will prevent condensation, prevent entry of fluids, and protect threads.

17 Quality assurance

17.1 General

Quality system programs shall be established and operated to confirm that containers will be produced in accordance with the qualified design.

Quality systems shall be in accordance with one of the following options unless otherwise specified by the AHJ:

a) **Option 1:** Approved Quality System. Quality management systems shall be registered for compliance with the appropriate sections of ISO – 9001 by an accredited registrar. Other systems that incorporate ISO 9001, such as ISO/TS 16949, are acceptable.

b) **Option 2:** Independent Inspection. The manufacturer shall engage an independent inspector with responsibilities for inspection and review of the manufacturer's quality system.

17.2 Independent inspection (Option 2)

The independent inspection requirements shall be as follows:

a) The manufacturer shall arrange independent inspection of container production and testing. The independent inspector shall be engaged by a nationally recognized independent inspection agency.

b) The manufacturer's quality system manual shall document all elements, requirements, and provisions of the manufacturer's quality system. At a minimum, the manual shall address policies for design, purchasing, process control, inspection, test, and configuration management. The system shall be described in a comprehensive and orderly manner in the form of written policies, procedures, and instructions that will permit a clear and consistent understanding of the manufacturer's intent with respect to quality assurance.

c) The independent inspector shall perform or witness the inspections required in Clause 9.1, review the quality system manual for completeness, and monitor the quality system of the manufacturer in accordance with Clause 9.2. The independent inspector shall notify the manufacturer of deficiencies in the quality system and shall maintain a written record of deficiencies and corrective action.

18 Design qualification tests

18.1 General

Qualification testing shall be conducted on finished containers that are representative of normal production (including a protective coating if part of the design unless otherwise specified) and complete with identification marks. All design qualification tests shall be conducted or witnessed by the independent inspection or test agency. Test records shall be kept on file by the container manufacturer.

18.2 Test requirements

Containers representative of each design and design change shall successfully meet the requirements of a Category A, Category B, or Category C design qualification test.

Category A design qualification requirements are prescribed in Table 3, using procedures found in Clause 18.3.

Category B design qualification requirements are prescribed in Table 4, using procedures found in Clause 18.3 and Clause 18.5.

Category C design qualification requirements are prescribed in Table 3, using procedures found in Clause 18.3 and with the conditions and limitations found in Clause 18.6.

Container pressure during cycle testing shall be monitored by a transducer located after the container, i.e., the container shall be located between the pressure source and the transducer. Alternatively, it shall be demonstrated to the satisfaction of the independent inspection agency or demonstrated by the independent test agency that the pressure measured at the maximum cycle pressure is the “true” pressure, i.e., there is no pressure drop between the container and the pressure transducer. This may be achieved by incorporating a 1 second hold in the cycle at the maximum pressure and the minimum pressure. The pressure cycle rate during cycle testing shall not exceed the rate at which pressure verification was performed.

If not otherwise specified, the pressure cycling rate shall be at the discretion of the manufacturer but shall not exceed 10 cycles per minute.

Caution shall be taken to confirm that the specified test temperature is maintained.

Composite reinforcement on containers subjected to qualification tests shall be fully cured. Completeness of cure shall be verified on all units used in qualification tests.

Table 3
Test requirements for Category A and C containers
(See Clauses 10.9 and 18.2.)

Clause	Test Name	Type 1	Type 2	Type 3	Type 4
18.3.2	Ambient cycling test	•	•	•	•
18.3.3	Environmental test		•	•	•
18.3.4	Extreme temperature cycling test	•	•	•	•
18.3.5	Hydrostatic burst test	•	•	•	•
18.3.6	Composite flaw tolerance test		•	•	•
18.3.7	Drop test		•	•	•
18.3.8	Fire test	•	•	•	•
18.3.9	Accelerated stress rupture test	•	•	•	•
18.3.10	High strain rate impact test	•	•	•	•
18.3.11	Permeation test				•
18.3.12	Boss torque test				•
18.3.13	Hydrogen gas cycling test	•	•	•	•
18.3.14	Leak before break test	•	•		

Table 4
Test requirements for Category B containers
(See Clauses 10.9 and 18.2.)

Clause	Test Name	Type 1	Type 2	Type 3	Type 4
18.5.2	Ambient cycling test (per 18.3.2)	•	•	•	•
18.5.3	Hydrostatic burst test (per 18.3.5)	•	•	•	•
18.5.4	Container test for performance durability	•	•	•	•
18.3.8	Fire test	•	•	•	•
18.5.5	Permeation test (per 18.3.11)				•
18.5.6	Container test for expected on-road performance	•	•	•	•

18.3 Category A and C: design qualification tests

18.3.1 Test requirements

Category A and C containers shall be subjected to the tests specified in Clause 18.3.

18.3.2 Ambient cycling test

18.3.2.1 Sampling

Three finished containers shall be subjected to the ambient pressure cycle test.

18.3.2.2 Procedure

Pressure cycling shall be performed in accordance with the following procedure:

a) Fill the container to be tested with a non-corrosive fluid such as oil, inhibited water, or glycol.
b) Cycle the pressure in the container between 2 (±1) MPa to at least 125 percent of nominal working pressure at a rate not greater than 10 cycles per minute for the following number of cycles:
    i) Category A containers: Number of cycles equivalent to 750 times the service life of the container in years.
    ii) Category B containers: Number of cycles equivalent to 5 500, 7500, or 11 000 cycles for a 15-year service life.
    iii) Category C containers: Number of cycles equivalent to 1 125 times the service life of the container in years.

18.3.2.3 Acceptable results

a) Category A containers shall not leak before reaching a number of cycles equivalent to 750 times the service life of the container in years.
b) Category B containers shall not leak before reaching a number of cycles equivalent to 5 500, 7500, or 11 000 cycles for a 15-year service life.
c) Category C containers shall not leak before reaching a number of cycles equivalent to 1 125 times the service life of the container in years.
d) For Types 2, 3, and 4 containers, the fibers in the overwrap are not allowed to fail.
e) Category A containers exceeding a number of cycles that is 1 500 times the service life in years, or Category B containers exceeding 22 000 cycles, or Category C containers exceeding a number of cycles that is 2 250 times the service life in years, are permitted to fail by leak or rupture.

Category A and C containers that do not fail within a number of cycles that is 1 500 times the service life in years, or Category B containers exceeding 22 000 cycles, or Category C containers exceeding 2 250 cycles times the service life in years, shall be destroyed either by continuing until failure occurs or by hydrostatically pressurizing to burst.

Note: It is acceptable for the pressurizing fluid to rise above the ambient temperature as long as the temperature of the test chamber does not exceed the ambient temperature requirement.

18.3.3 Environmental test

18.3.3.1 Sampling

One finished container shall be subjected to the environmental test ~~tested~~, including coating if applicable.

18.3.3.2 Procedure

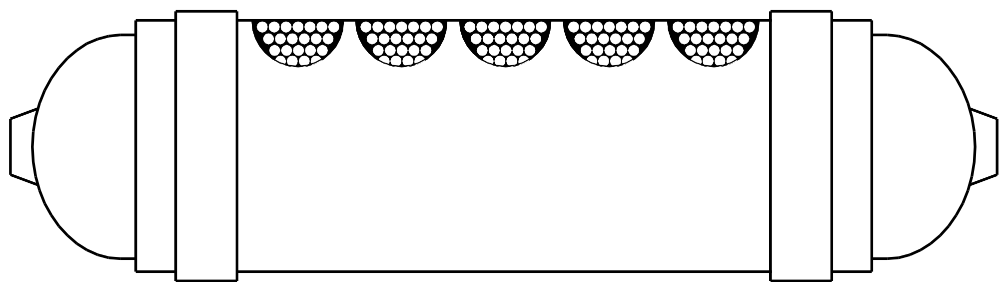
The environmental test shall be performed in accordance with the following procedure.

18.3.3.2.1 General

The upper section of the container shall be divided into five distinct areas and marked for pendulum impact preconditioning and fluid exposure (see Figure 1). The areas shall be nominally 10 cm in diameter. While convenient for testing, the areas need not be oriented along a single line, but shall not overlap.

Although preconditioning and other fluid exposure is performed on the cylindrical section of the container, all of the container, including the domed sections, shall be as resistant to the exposure environments as the exposed areas.

Figure 1
Container orientation and layout of exposure areas
(See Clause 18.3.3.2.1 and 18.3.3.2.3)



18.3.3.2.2 Pendulum impact preconditioning

The impact body shall be of steel and have the shape of a pyramid with equilateral triangle faces and a square base, the summit and the edges being rounded to a radius of 3 mm. The center of percussion of the pendulum shall coincide with the center of gravity of the pyramid; its distance from the axis of rotation of the pendulum shall be 1 m. The total mass of the pendulum referred to its center of percussion shall be 15 kg. The energy of the pendulum at the moment of impact shall be not less than 30 Nm and as close to that value as possible.

During pendulum impact, the container shall be held in position by the end bosses or by the intended mounting brackets. Each of the five areas identified in Figure 1 shall be preconditioned by impact of the pendulum body summit at the center of the area. The container shall be unpressurized during preconditioning.

18.3.3.2.3 Environmental fluids for exposure

Each marked area shall be exposed to one of five solutions. The five solutions are:

a) sulfuric acid – 19 percent solution by volume in water;
b) sodium hydroxide – 25 percent solution by weight in water;
c) methanol/gasoline – 5/95 percent concentration of M5 fuel meeting the requirements of ASTM D4814;
d) ammonium nitrate – 28 percent by weight in water; and
e) windshield washer fluid (50 percent by volume solution of methanol and water).

When exposed, the test sample will be oriented with the exposure area uppermost. A pad of glass wool approximately 0.5 mm thick and between 90 and 100 mm in diameter shall be placed on the exposure area. Apply an amount of the test fluid to the glass wool sufficient to wet the pad evenly across its surface and through its thickness for the duration of the test, and sufficient to confirm that the concentration of the fluid is not changed significantly during the duration of the test.

18.3.3.2.4 Pressure cycle and pressure hold

Containers shall be hydraulically pressure cycled between 2 (± 1) MPa and at least 125 percent of nominal working pressure for a total of 3 000 cycles. The maximum pressurization rate shall be 2 750 kPa per second. After pressure cycling, containers shall be pressurized to 125 percent of nominal working pressure and held at that pressure a minimum of 24 hours and until the elapsed exposure time (pressure cycling and pressure hold) to the environmental fluids equals 48 hours.

18.3.3.3 Acceptable results

Following the above test sequence, the residual burst strength of the container shall be no less than 180 percent of nominal working pressure when tested in accordance with the hydrostatic burst test in Clause 18.3.5.

18.3.4 Extreme temperature cycling test

18.3.4.1 Sampling

One finished container shall be subjected to the extreme temperature cycling test.

18.3.4.2 Procedure

The extreme temperature cycle test shall be performed in accordance with the following procedure:

a) Stabilize the container at zero pressure and 85°C degrees or higher.

b) Hydraulically pressure cycle between 2 (± 1) MPa and at least 125 percent of nominal working pressure for 4 000 cycles. The temperature limits specified in (a) shall be met on the container skin and in the working fluid in the container throughout the cycling.

c) Stabilize the container at zero pressure and ambient conditions.

d) Stabilize the container at zero pressure and −40°C degrees or lower.

e) Hydraulically pressure cycle between 2 (± 1) MPa and at least 80 percent of nominal working pressure for 4 000 cycles. The temperature limits specified in (d) shall be met on the container skin and in the working fluid in the container throughout the cycling.

The cycling rate shall not exceed 10 cycles per minute.

18.3.4.3 Acceptable results

Following pressure cycling at extreme temperatures, the container shall not leak or rupture and the residual burst strength of the container shall be no less than 180 percent of nominal working pressure when tested in accordance with the hydrostatic burst test in Clause 18.3.5.

18.3.5 Hydrostatic burst test

18.3.5.1 Sampling

Three finished containers shall be subjected to the hydrostatic burst test.

18.3.5.2 Procedure

The hydrostatic burst test shall be performed in accordance with the following procedure:

The rate of pressurization shall not exceed 1 400 kPa per second at pressures in excess of 150 percent of the nominal working pressure. If the rate of pressurization at pressures in excess of 150 percent of the nominal working pressure exceeds 350 kPa per second, then either the container shall be placed schematically between the pressure source and the pressure measurement device or there shall be a 5-second hold at the minimum required burst pressure.

18.3.5.3 Acceptable results

The actual burst pressure shall be recorded.

The minimum required burst pressure shall be at least 225 percent of the nominal working pressure and in no case less than the value necessary to meet the burst/nominal working pressure ratio requirement of Clause 7.1, for Type 1 containers or the stress ratio requirement of Clause 7.3.2, when analyzed in accordance with the requirements of Clause 7.3.1.

18.3.6 Flaw tolerance test

18.3.6.1 Sampling

One finished container shall be subjected to the flaw tolerance test.

18.3.6.2 Procedure

The flaw tolerance test shall be performed in accordance with the following procedure:

For Type 1 containers:

a) One uncoated container shall have two flaws in the longitudinal direction cut into the container sidewall. One flaw shall be a minimum 25 mm long and minimum 0.42 mm in depth and the other flaw shall be a minimum 200 mm long and minimum 0.25 mm in depth.

b) The flawed container shall then be pressure cycled, from 2 (± 1) MPa to at least 125 percent of the nominal working pressure for a number of cycles equivalent to 750 times the service life of the container in years for Category A containers, or to 1 125 times the service life of the container in years for Category C containers.

For Types 2, 3, and 4 containers:

c) One uncoated container shall have two flaws in the longitudinal direction cut into the composite sidewall. One flaw shall be a minimum 25 mm long and minimum 1.25 mm in depth and the other flaw shall be a minimum 200 mm long and minimum 0.75 mm in depth.

d) The flawed container shall then be pressure cycled, from 2 (± 1) MPa to at least 125 percent of the nominal working pressure for a number of cycles equivalent to 750 times the service life of the container in years for Category A containers, or to 1 125 times the service life of the container in years for Category C containers.

18.3.6.3 Acceptable results

The container shall not leak or rupture within the first 3 000 cycles, but may fail by leakage up to the maximum number of cycles. All containers that complete this test shall be destroyed.

18.3.7 Drop test

18.3.7.1 Sampling

One or more finished containers shall be subjected to the drop test.

18.3.7.2 Procedure

For Types 2, 3, and 4 containers only:

a) One or more finished containers shall be drop tested at ambient temperature without internal pressurization or attached valves. The surface onto which the containers are dropped shall be a smooth, horizontal concrete pad or flooring. One container shall be dropped in a horizontal position with the lowest point of the container no less than 1.83 m above the surface onto which it is dropped. One container shall be dropped vertically on each end at a sufficient height above the floor or pad so that the potential energy is 488 joules, but in no case shall the height of the lower end be greater than 1.83 m. One container shall be dropped at a 45-degree angle onto a dome from a height such that the center of gravity is at 1.83 m; however, if the lower end is closer to the ground than 0.6 m, the drop angle shall be changed to maintain a minimum height of 0.6 m and a center of gravity of 1.83 m. The container(s) shall be allowed to bounce on the concrete pad or flooring after the initial impact. No attempt shall be made to prevent this secondary impacting, but the container may be prevented from toppling during the vertical drop test.

b) Following the drop impact, the container(s) shall be pressure cycled, 2 (± 1) MPa to at least 125 percent of nominal working pressure for a number of cycles equivalent to 750 times the service life of the container in years for Category A containers, or to 1 125 times the service life of the container in years for Category C containers.

18.3.7.3 Acceptable results

The container(s) shall not leak or rupture within the first 3 000 cycles, but may fail by leakage up to the maximum number of cycles. All containers that complete this test shall be destroyed.

18.3.8 Fire test

18.3.8.1 Sampling

One finished container shall be subjected to the fire test.

18.3.8.2 Procedure

The fire test shall be performed in accordance with the following procedure:

18.3.8.2.1 General

The fire test shall be designed to demonstrate that finished containers complete with the pressure relief devices specified in the design along with additional relevant features including the venting system (such as the vent line and vent line covering) and any shielding affixed directly to the container (such as thermal wraps and/or coverings/barriers over the pressure relief device) will prevent the rupture of the container when tested under the specified fire conditions. The specified fire conditions include both localized and engulfing fire threats.

Extreme caution shall be exercised during fire testing. Container rupture could occur.

Testing shall be conducted with ambient temperatures between −7 ^{o}C and 43 ^{o}C.

18.3.8.2.2 Container set-up

The localized fire exposure area shall be the area on the container farthest from the pressure relief device(s). If the container is not cylindrically symmetrical, it shall be oriented over the fire source in a worst-case configuration. The container shall only include thermal shielding or other mitigation devices affixed directly to the container that are used in all vehicle applications. Venting system(s) (such as the vent line and vent line covering) and/or coverings/barriers over the pressure relief device(s) shall be included in the test if they are anticipated for use in any application. If a container is tested without representative components, then retesting of that container shall be required if a vehicle application specifies the use of these types of components.

If a specific vehicle installation configuration is specified and the qualification of the system is limited to that specific vehicle installation configuration, then the test setup may also include other vehicle components in addition to the hydrogen storage system. These vehicle components (such as shielding or barriers, which are permanently attached to the vehicle's structure by means of welding or bolts and not affixed to the storage system) shall be included in the test setup in the vehicle-installed configuration relative to the hydrogen storage system. This localized fire test shall be conducted on the worst-case localized fire exposure areas based on the four fire orientations: fires originating from the direction of the passenger compartment, cargo/luggage compartment, wheel wells, or ground-pooled gasoline.

Containers shall be pressurized with hydrogen to nominal working pressure, pressure compensated for ambient test temperature, and placed horizontally with the container bottom approximately 100 mm above the fire source. The fire source shall initiate within a 250 ± 50 mm longitudinal expanse positioned under the localized exposure area of the container. The width of the fire source shall encompass the entire diameter of the container.

18.3.8.2.3 Fire source

The fire source shall consist of LPG burners configured to produce a uniform minimum temperature on the container defined as a moving 1-minute average per thermocouple with a minimum 5 thermocouples covering the length of the container up to 1.65 m maximum (at least 2 thermocouples within the localized fire area, and at least 3 thermocouples equally spaced and no more than 50 cm apart in the remaining area) located 25 ± 10mm from the outside surface of the container along its longitudinal axis. At the option of the manufacturer or independent inspection or testing facility, additional thermocouples may be located at pressure relief device sensing points or any other locations for optional diagnostic purposes.

Wind shields shall be utilized to allow uniform heating.

18.3.8.2.4 Test requirements

The test temperature profile for the localized fire test is shown in Figure 2 and detailed thermal requirements are provided in Table 5. The temperature at the thermocouples in the localized fire area shall be increased continuously to at least 300 ^{o}C within 1 minute of ignition, to at least 600 ^{o}C within 3 minutes of ignition, and a rolling average temperature of at least 600 ^{o}C shall be maintained for the next 7 minutes. Then, within the next 2-minute interval, the temperature at the thermocouples in the fire source shall be increased to at least 800 ^{o}C and the fire source shall be extended to produce a rolling average temperature of at least 800 ^{o}C along the entire length and width of the container (engulfing fire). Note that the temperature outside the region of the initial fire source is not specified during the initial 10 minutes from the time of ignition.

Figure 2
Minimum temperature during the fire test
(See Clause 18.3.8.2.4)

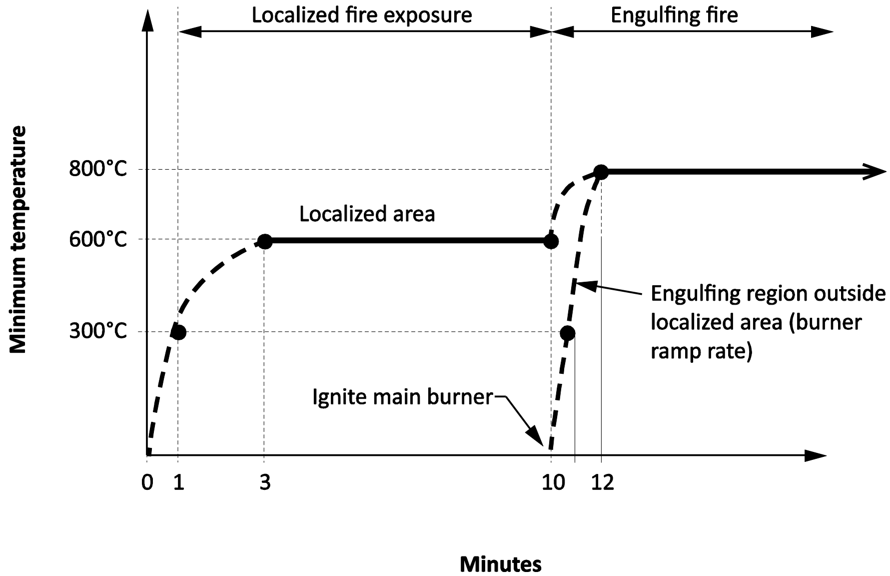


Table 5
Fire test procedure description
(See Clause 18.3.8.2.4)

	Localized Fire Region	**Time Period**	**Engulfing Fire Region (Outside the Localized Fire Region)**
Action *Minimum Temperature* *Maximum Temperature*	Ignite Burners Not specified Less than 900°C	0-1 Minute	No Burner Operation Not specified Not specified
Action *Minimum Temperature* *Maximum Temperature*	Increase Temperature and Stabilize Fire for Start of Localized Fire Exposure Greater than 300°C Less than 900°C	1-3 Minutes	No Burner Operation Not specified Not specified
Action *Minimum Temperature* *Maximum Temperature*	Localized Fire Exposure Continues 1-minute Rolling Average Greater Than 600°C 1-minute Rolling Average Less Than 900°C	3-10 Minutes	No Burner Operation Not specified Not specified
Action *Minimum Temperature* *Maximum Temperature*	Increase Temperature 1-minute Rolling Average Greater Than 600°C 1-minute Rolling Average Less Than 1 100°C	10-11 Minutes	Main Burner Ignited at 10 Minutes Not specified Less than 1 100°C
Action *Minimum Temperature* *Maximum Temperature*	Increase Temperature and Stabilize Fire for Start of Engulfing Fire Exposure 1-minute Rolling Average Greater Than 600°C 1 minute Rolling Average Less Than 1 100 °C	11-12 Minutes	Increase Temperature and Stabilize Fire for Start of Engulfing Fire Exposure Greater than 300°C Less than 1 100°C
Action *Minimum Temperature* *Maximum Temperature*	Engulfing Fire Exposure Continues 1-minute Rolling Average Greater Than 800°C 1 minute Rolling Average Less Than 1 100°C	12 Minutes - end of test	Engulfing Fire Exposure Continues 1-minute Rolling Average Greater than 800°C 1-minute Rolling Average Less than 1 100°C

18.3.8.3 Acceptable results

The container shall be held at temperature (engulfing fire condition) until the hydrogen vents through the pressure relief device(s) and the test shall continue until the pressure falls to less than 1 MPa. The venting shall be continuous (without interruption) and the container shall not rupture. An additional release through leakage (not including release through the pressure relief device(s)) that results in a flame with length greater than 0.5 m beyond the perimeter of the applied flame shall not occur.

The arrangement of the fire shall be recorded in sufficient detail to confirm the rate of heat input to the container is reproducible. The results shall include the elapsed time from ignition of the fire to the start of venting through the pressure relief device(s) and the maximum pressure and time of evacuation until a pressure of less than 1 MPa is reached. Thermocouple temperatures and container pressure shall be recorded at intervals of every 10 seconds or less during the test. Any failure to maintain specified temperature requirements during a test invalidates the result.

18.3.9 Accelerated stress rupture test

18.3.9.1 Sampling

One finished Type 2, 3 or 4 container shall be subjected to the accelerated stress rupture test.

18.3.9.2 Procedure

The accelerated stress rupture test shall be performed in accordance with the following procedure:

The container shall be hydrostatically pressurized to 125 percent of nominal working pressure while at a temperature of 85 ^{o}C. The container shall be held at this pressure and temperature for 1 000 hours.

18.3.9.3 Acceptable results

The container shall exceed 75 percent of the minimum burst pressure when tested in accordance with the hydrostatic burst test in Clause 18.3.5.

The residual burst strength of the container shall be no less than 180 percent of nominal working pressure when tested in accordance with the hydrostatic burst test in Clause 18.3.5.

18.3.10 High strain rate impact test

18.3.10.1 Sampling

One finished container shall be subjected to the high strain rate impact test.

18.3.10.2 Procedure

A container shall be pneumatically pressurized to nominal working pressure with nitrogen, helium, or hydrogen and be impacted by either:

a) a 7.62 mm diameter armor-piercing projectile (specified as 7.62x51mm NATO, armor piercing bullet) with a nominal velocity of 850 m/s. The bullet shall be fired from a distance of no more than 45 m; or

b) a steel projectile having a minimum hardness of 870 Hv, with a diameter between 6.08 mm and 7.62 mm, having a mass of between 3.8 g and 9.75 g, a conical shape with a nose angle of 45°, nominal velocity of 850 m/s, and impacting with a minimum energy of 3 300 J.

The projectile shall impact the sidewall of the container at a 90° angle but shall not be required to pass through the sidewall of the container.

18.3.10.3 Acceptable results

The container shall not rupture.

18.3.11 Permeation test

18.3.11.1 Sampling

One finished container shall be subjected to the permeation test.

18.3.11.2 Procedure

The permeation test shall be performed in accordance with the following procedure:

Containers may be located in enclosed spaces for extended periods of time. Permeation of gas from the container shall be considered in the design.

This test shall only be required on Type 4 containers.

One container shall be filled with hydrogen to the nominal working pressure, placed in an enclosed sealed container at ambient temperature, and monitored for 500 hours to establish a steady state permeation rate.

18.3.11.2 Acceptable results

The steady state permeation rate for hydrogen gas shall be less than 6.0 Ncc of hydrogen per hour per liter water capacity.

Note: *For the purposes of this Standard, the combination of permeation and leakage, if below the allowable permeation rate per Clause 18.3.11, constitutes compliance with the permeation requirements, and if above the allowable permeation rate per Clause 18.3.11, constitutes lack of compliance with the permeation requirements.*

18.3.12 Boss torque test

18.3.12.1 Sampling

One finished container shall be subjected to the permeation test.

18.3.12.2 Procedure

This test shall only be required on Type 4 containers.

One container shall be preconditioned with the boss subjected to twice the installation torque specified for the fittings. The container shall then be subjected to Clause 11.3.

18.3.12.3 Acceptable results

Any gas detected beyond the allowable permeation rate shall be cause for rejection.

18.3.13 Hydrogen gas cycling test

18.3.13.1 Sampling

One finished container shall be subjected to the hydrogen gas cycling test.

18.3.13.2 Procedure

The hydrogen gas cycling test shall be performed in accordance with the following procedure:

The container shall be pressure cycled using hydrogen from 2 (± 1) MPa to at least 125 percent of nominal working pressure for 1 000 cycles. The end boss at the valve end (the end where the fill/discharge occurs) may be grounded. Each cycle shall consist of filling and venting of the container. The fill rate shall not exceed 60 g/s and the maximum allowable gas temperature. The defueling rate shall be specified by the container manufacturer and shall not allow the gas temperature to be lower than the minimum allowable gas temperature as specified in Clause 4.4.

The first 500 cycles shall be conducted at ambient temperature, followed by a static hold at 115 percent of nominal working pressure at 55 ^{o}C for a minimum of 30 hours. The second 500 cycles shall be conducted with the container at an ambient temperature of 50 ^{o}C.

18.3.13.3 Acceptable results

Following completion of the test, the container shall meet the requirements of the leak test in Clause 11.3. Type 4 containers shall then be sectioned and the liner and liner/end boss interface inspected for evidence of any deterioration, such as fatigue cracking, disbonding of plastic, deterioration of seals, or damage from electrostatic discharge.

18.3.14 Leak before break test

18.3.14.1 Sampling

One finished container shall be subjected to the leak before break test.

18.3.14.2 Procedure

The leak before break test shall be performed in accordance with the following procedure:

This test only applies to Type 1 and Type 2 containers.

The containers shall be pressure cycled between not more than 2 (± 1) MPa and at least 150 percent of nominal working pressure at a rate not to exceed 10 cycles per minute in accordance with Clause 18.3.2.

18.3.14.3 Acceptable results

All containers shall either fail by leakage or exceed 45 000 pressure cycles.

18.4 Change of design

Category A and C container designs that are sufficiently similar to an existing fully qualified design shall be permitted to be qualified through a reduced test program as defined in Table 6.

Design changes not falling within the guidelines in Table 6 shall be qualified as an original design. If a minor design change is not defined in Table 6, then the independent inspection or test agency shall determine the level of reduced testing required for requalification.

A design approved by a reduced series of tests (a design change) shall not be used as the sole basis for a second design change approval with a reduced set of tests (i.e., multiple changes from an original design are not permitted). However, if a test has been conducted on a design change (X) that falls within the testing requirements for a second design change (Y), then the test result for first design change (X) may be applied to the new design change (Y) test program.

Table 6
Test requirements for designs and design changes for Category A and C containers
(See Clause 18.4.)

Test	Original Design	Fiber Material or Manufacturer (1)	Resin System Material or Manufacturer	Liner or Metal Container Material or Manufacturer (11)	Dia. ≤20% Change (6)	Dia. >20% Change (6)	Service Pressure ≤20% Change (6)	Length ≤≤50% Change	Length >50% Change	Integral Mounting Brackets & Valve Protection Shrouds	Pressure Relief Devices or Valves	External Coating	Boss Material or Geometry
Ambient cycling test (Clause 18.3.2)	X	X	X(13)	X	X(13)	X	X(13)	X(13)	X(13)	X(13)			X(13)
Environmental test (3) (Clause 18.3.3)	X	X(4)	X(9)									X	
Extreme temperature cycling (3) (Clause 18.3.4)	X	X(4)	X(9)	X									
Hydrostatic burst test (Clause 18.3.5)	X	X	X(13)	X(14)	X(13)	X	X(13)	X(13)	X(13)	X(13)			X(13)
Flaw tolerance test (3) (Clause 18.3.6)	X		X(9)										
Drop test (3) (Clause 18.3.7)	X	X	X(9)	X(5)	X	X			X				
Fire test (Clause 18.3.8)	X	X		X		X		X(2)	X		X(7)		
Accelerated stress rupture test (3) (Clause 18.3.9)	X	X	X										
High strain rate impact test (Clause 18.3.10)	X	X	X(9)	X(14)	X(8)	X		X(15)					
Permeation test (5) (Clause 18.3.11)	X			X									

Test	Original Design	Fiber Material or Manufacturer (1)	Resin System Material or Manufacturer	Liner or Metal Container Material or Manufacturer (11)	Dia. ≤20% Change (6)	Dia. >20% Change (6)	Service Pressure ≤20% Change (6)	Length ≤≤50% Change	Length >50% Change	Integral Mounting Brackets & Valve Protection Shrouds	Pressure Relief Devices or Valves	External Coating	Boss Material or Geometry
Boss torque test (Clause 18.3.12)	X										X(12)		X
Hydrogen gas cycling test (Clause 18.3.13)	X			X									X (10)
Leak before break (Clause 18.3.14)	X	X		X		X							

Notes:

1) *Change of fiber type, e.g. glass to carbon is not applicable. Change of design applies only to changes of materials properties or manufacturer within a fiber type.*

2) *Fire test not required, provided safety relief devices or device configuration passed the required fire test on a container with equal or greater internal water volume.*

3) *Test required only on composite reinforced containers.*

4) *Not applicable to carbon fiber designs.*

5) *Test required only for Type 4 containers.*

6) *When changes in diameter or pressure are made, the structural wall elements shall be operating at the same or lower nominal stress levels as the original design (e.g., if pressure or diameter increase, the wall thickness will increase proportionally.)*

7) *Required if the new valve design has reduced relief channel flow area compared with previously qualified valves or if the mass of the valve and PRD increase by more than 30 percent or when pressure relief device is changed.*

8) *Test required only if diameter decreases.*

9) *Test not required when resins of the same chemical and physical properties are substituted*

10) *Test required for Type 4 containers when the boss to liner interface is affected by design changes.*

11) *Change of liner or metal container material, e.g. steel to aluminum is not applicable. Change of design applies only to changes of materials properties or manufacturer within a material type.*

12) *Only applicable for an increase in valve torque.*

13) *Only one unit required for design change; may be done as part of the Batch test.*

14) *Test not required for Type 4 containers*

15) *Test only required when resulting container sidewall length is less than the diameter*

18.5 Category B: design qualification tests

18.5.1 General test requirements

Category B containers shall be subjected to the tests specified in Clause 18.5.

Note: *Containers subjected to these tests are intended to be integrated into a compressed hydrogen storage system, including all closure devices (such as shut-off valves, check valves, pressure relief devices, etc.) and piping, and are expected to meet the additional test requirements (Verification Test for Expected On-Road Performance [Sequential Pneumatic Tests], Verification Test for Service Terminating Performance in Fire, and Verification Test for Closure Durability) in the UN GTR or SAE J2579.*

18.5.2 Ambient cycling test

Containers shall be subjected to the pressure cycling test specified in Clause 18.3.2.

18.5.3 Hydrostatic burst test

Containers shall be subjected to the burst test specified in Clause 18.3.5. The manufacturer shall supply documentation (measurements and statistical analyses) that establish the midpoint burst pressure of new containers.

All containers tested shall have a burst pressure within ±10 percent of the midpoint and greater than 225 percent of nominal working pressure and in no case less than the value necessary to meet the burst/nominal working pressure ratio requirement of Clause 7.1, for Type 1 containers, or the stress ratio requirement of Clause 7.3.2, when analyzed in accordance with the requirements of Clause 7.3.1. Actual burst pressure shall be recorded.

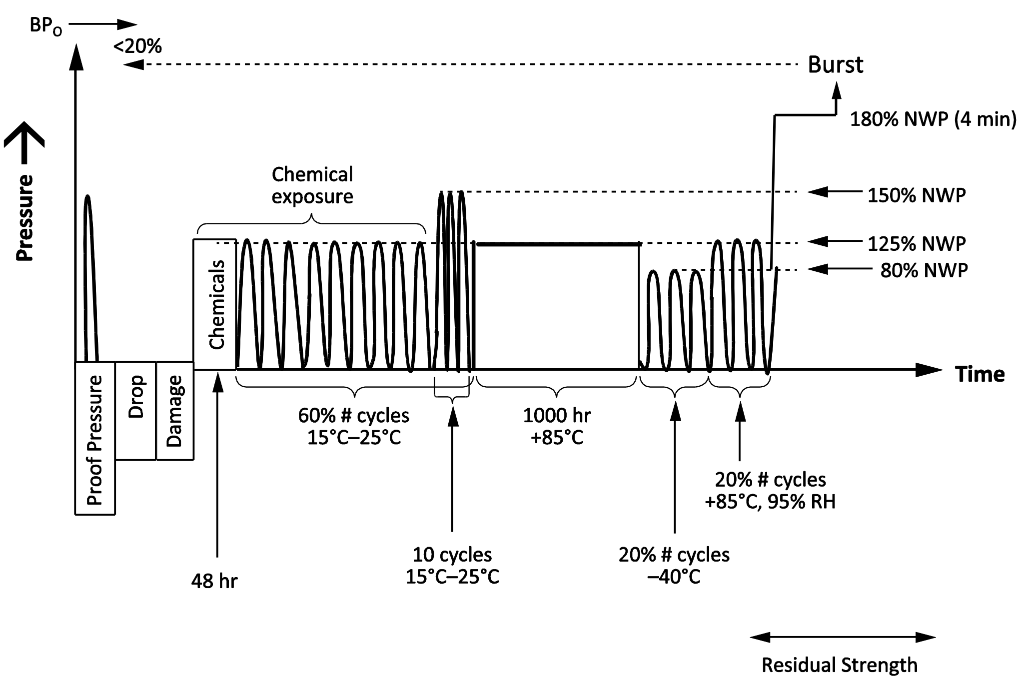
18.5.4 Container test for performance durability

18.5.4.1 Test requirements

If all three pressure cycle life measurements determined per Clause 18.5.2 are greater than 11 000 cycles or if they are all within ±25 percent of each other, then only one container shall be subjected to the tests specified in Clause 18.5.4. Otherwise, three containers shall be tested.

The container(s) shall not leak during the following sequence of tests, which are applied in series to an individual container(s) and which are illustrated in Figure 3.

Figure 3
Verification test for performance durability
(See Clause 18.5.4.1.)



Note: *BP_o is the midpoint burst pressure of new containers.*

18.5.4.2 Proof pressure test

Containers shall be subjected to the proof pressure test specified in Clause 11.2. If a container has previously undergone a proof pressure test in manufacture, then the container shall be exempt from this test.

18.5.4.3 Drop test

Containers shall be subjected to the drop test conditioning specified in Clause 18.3.7.2(a).

18.5.4.4 Surface damage test

Containers shall be subjected to the surface flaw conditioning specified in Clause 18.3.6.2(a) or 18.3.6.2(c), except the flaws shall be introduced in the bottom surface of the container and the 25 mm long cut shall be situated toward the valve end of the container and the 200 mm long cut shall be situated opposite the valve end of the container.

The upper surface of the container shall be subjected to the pendulum impact conditioning specified in Clauses 18.3.3.2.1 and 18.3.3.2.2, except that the container shall be preconditioned at −40°C for 12 hours prior to the pendulum impacts.

18.5.4.5 Chemical exposure and ambient pressure cycling

Containers shall be subjected to the chemical conditioning specified in Clause 18.3.3.2.3, except that the container shall be held at ambient temperature and 125 percent of nominal working pressure for 48 hours before the container is subjected to further testing.

Containers shall be subjected to the pressure cycling test specified in Clause 18.3.2 to 60 percent of 5 500, 7 500, or 11 000 cycles, as appropriate. Chemical exposure shall be discontinued by removing the glass wool pads and rinsing the container surface with water before the last 10 cycles, which shall be conducted to 150 percent of nominal working pressure.

18.5.4.6 High temperature static pressure test

Containers shall be pressurized to 125 percent of nominal working pressure while at a temperature of 85°C. The container shall be held at this pressure and temperature for 1 000 hours.

18.5.4.7 Extreme temperature pressure cycling test

Containers shall be pressure cycled at −40°C or lower to 80 percent of nominal working pressure in accordance with the test procedure specified in Clause 18.3.4.2(c), (d), and (e), except that the container shall be cycled to 20 percent of 5 500, 7 500, or 11 000 cycles, as appropriate.

Containers shall be pressure cycled at 85°C or higher to 125 percent of nominal working pressure in accordance with the test procedure specified in Clause 18.3.4.2(a) and (b), except that the container shall be cycled at 95 percent relative humidity and to 20 percent of 5 500, 7 500, or 11 000 cycles, as appropriate.

18.5.4.8 Hydraulic residual pressure test

Containers shall be pressurized to 180 percent of nominal working pressure and held for four minutes. The container shall not rupture.

18.5.4.9 Residual burst test

Containers shall be subjected to the burst test specified in Clause 18.3.5. The container shall burst at a pressure that is at least 80 percent of the burst pressure determined in Clause 18.3.5.

18.5.5 Permeation test

Type 4 containers shall be subjected to the permeation test specified in Clause 18.3.11 or with a system level permeation test in accordance with the UN GTR, SAE J2579, or equivalent fuel cell vehicle regulations or standards.

18.5.6 Container test for expected on-road performance

In order for a Category B container to be fully qualified for on-road vehicle usage, a container test shall be conducted at a system level in accordance with the UN GTR, SAE J2579, or equivalent fuel cell vehicle regulations or standards.

18.6 Category C: design qualification conditions and limitations

18.6.1 Marking information

Clause 16.1.2 (a) (v) does not apply.

18.6.2 Material tests for steel containers and liners

If the container or liner is made of steel, appropriate material tests in accordance with Clauses 10.2 to 10.4 of ISO 9809-1, or Clauses 10.2 to 10.4 of ISO 9809-2, shall be carried out on one liner. The tensile strength shall meet the manufacturer's design specifications. For Type 1 and Type 2 containers the steel elongation shall be at least 14 percent. For Type 3 containers the tensile strength and elongation shall meet the manufacturer's design specifications.

Stainless steels SUS316L, AISI316L and AISI316 having >12 percent nickel composition and <0.1 percent magnetic phases by volume are suitable for hydrogen service.

Note: Further investigation is required to confirm the need to retain the >12% nickel composition requirement.

18.6.3 Material tests for aluminum alloy containers and liners

For Type 1 containers and Type 2 liners using aluminum alloy, appropriate material tests as required in ISO 7866 Clauses 10.2 and 10.3, as well as Annexes A and B shall be carried out on one container or liner. The materials properties shall meet the manufacturer's design specifications. The elongation shall be at least 12%. For Type 3 liners using aluminum alloy, materials tests as required in ISO 7866 Clause 10.2 and Annex B shall be carried out on one liner. The materials properties, including elongation, shall meet the manufacturer's design specifications.

Aluminum alloys A6061-T6, A6061-T62, A6061-T651 and A6061-T6511 are suitable for hydrogen service.

18.7 Qualification test results

A record of all tests for each design describing test setup, procedure, and results shall be kept on file by the container manufacturer. These records shall include the complete Inspector's Record and the information contained in Figure 4 and Figure 5 for each container design tested.

Figure 4
Container design information
(See Clause 18.7)

Container Type (check one): 1 _________ 2 _________ 3 _________ 4 _________

Manufacturer ____ Part No. ____________

Service Pressure _____________________ kPa

Hydrostatic Test Pressure _____________________ kPa

Autofrettage Pressure _____________________ kPa

Minimum Prescribed Burst Pressure ____________________ kPa

Volume (water) _____________________ liters

Length _____________________ mm

Inside Diameter _____________________ mm

Outside Diameter _____________________ mm

Liner Material _____________________

Boss Material _____________________

Filament Material _____________________

Resin System Material _____________________

Container Weight (nominal) _____________________ kg

Liner Weight (nominal) _____________________ kg

Composite Weight (nominal) _____________________ kg

Liner Sidewall Thickness (minimum) _____________________ mm

Liner Yield Strength (minimum) _____________________ MPa

Composite Longitudinal Thickness (nominal) _____________________ mm

Composite Circumferential Thickness (nominal) _____________________ mm

Composite Resin Shear Strength Water Boil (minimum) _____________________ MPa

Figure 5
Container stress distribution information
(See Clause 18.7)

	Stress distribution					
	Direction		**Distribution (MPa)**		**Distribution (%)**	
Pressure	**Long.**	**Circ.**	**Liner**	**Overwrap**	**Liner**	**Overwrap**
Zero	X	-				
	-	X				
Service	X	-				
	-	X				
Test	X	-				
	-	X				
Burst	X	-				
	-	X				

Inspector ____ Date __________________

19 Bibliography

AIAA (American Institute of Aeronautics and Astronautics)
ANSI/AIAA G-095-2004e
Guide to Safety of Hydrogen and Hydrogen Systems

CSA Group
ANSI/CSA CHMC 1-2014
Test methods for evaluating material compatibility in compressed hydrogen applications – Metals

ASME (American Society of Mechanical Engineers)
B31.12-2008
Hydrogen Piping and Pipelines

Annex A (informative)
Visual inspection

Note: *This informative Annex has been written in mandatory language to facilitate adoption by anyone wishing to do so.*

A.1 Methods for external visual inspection of compressed hydrogen gas vehicle (HGV) fuel containers and their installations

The inspection shall be performed by a qualified container inspector in accordance with the manufacturer's recommendations and the inspection procedures provided in Compressed Gas Association (CGA) C-6.4. Inspections shall be documented by the inspector and the documentation shall be made available to the AHJ upon request. Alternatively, containers may be inspected as installed using a non-destructive test method approved by the container manufacturer.

Containers without labels containing mandatory information, or with labels containing mandatory information that is illegible in any way, shall be removed from service. If the container can be positively identified by manufacturer and serial number, a replacement label supplied by the manufacturer may be applied to the container and it may remain in service.

A.2 Conditions requiring immediate inspections

Containers that have been involved in collisions, accidents, fires, or other events (for a more comprehensive list, see the Compressed Gas Association (CGA) C-6.4) that may cause damage shall be subjected to inspection procedures provided in CGA C-6.4. Containers that have not experienced any rejectable damage may be returned to service; otherwise, the container shall be destroyed per CGA C-6.4 or returned to the manufacturer for evaluation.

Annex B (informative)
Non-destructive examination

Note: *This informative Annex has been written in mandatory language to facilitate adoption by anyone wishing to do so.*

B.1 Non-destructive examination (NDE) defect size determination

For Type 1, 2, and 3 designs, the NDE defect size required for production inspection under Clause 11.1 shall be determined using a method as described under Clauses B.2, B.3, or other suitable methods.

B.2 NDE defect size by engineering critical assessment

For any metal whose fatigue performance is adversely affected by exposure to high-pressure hydrogen, all fatigue calculations shall use property data that has been determined by test in the representative hydrogen environment. ANSI/CSA CHMC 1 provides guidance for appropriate material test methods.

Calculations shall be performed in accordance with BS 7910-2005, section 8, using the following steps:

a) Fatigue cracks shall be modeled at the high stress location in the wall/liner as planar flaws.
b) The applied stress range at the fatigue sensitive site, due to a pressure between 10 percent of nominal working pressure and nominal working pressure, shall be established from the stress analysis as outlined above.
c) The bending and membrane stress component may be used separately.
d) The minimum number of pressure cycles is 750 times the service life in years.
e) The fatigue crack propagation data shall be determined in air in accordance with ASTM E647, or ISO 12108. The crack plane orientation shall be in the C-L direction (i.e. crack plane perpendicular to the circumferences and along the axis of the container), as illustrated in ASTM E399. The rate shall be determined as an average of three specimen tests. Where specific fatigue crack propagation data are available for the material and service condition, they may be used in the assessment.
f) The amount of crack growth in the thickness direction and in the length direction per pressure cycle shall be determined in accordance with the steps outlined in section 8.4 of BS 7910, by integrating the relationship between the rate of fatigue crack propagation, as established in (e) above, and the range of crack driving force corresponding to the applied pressure cycle.
g) The incremental crack dimension or stress intensity factor calculated in (f) should be compared with the limiting value, as per section 8.2.4 of BS 7910.
h) Using the above steps, calculate the maximum allowable defect depth and length that shall not cause the failure of the container during the service life due to either fatigue or rupture. The defect size for NDE shall be equal to or less than the calculated maximum allowable defect size for the design.

B.3 NDE defect size by flawed container cycling

When metals whose fatigue performance is adversely affected by exposure to high-pressure hydrogen are used, the flawed container cycling shall be performed using hydrogen gas meeting the purity limits in Clause 4.5.

For Type 1, 2, and 3 designs, three containers containing artificial defects that exceed the defect length and depth detection capability of the NDE inspection method required in Clause 11.1 shall be pressure cycled to failure in accordance with the test method in Clause 18.3.2. For Type 1 designs having a fatigue sensitive site in the cylindrical part, external flaws shall be introduced in the side wall. For Type 1 designs having the fatigue sensitive site outside the side wall and for Type 2 and 3 designs, internal flaws shall be introduced. Internal flaws may be machined prior to the heat treating and closing of the end of the container.

The containers shall not leak or rupture in less than a number of cycles equivalent to 750 times the service life of the container in years.

The allowable defect size for NDE shall be equal to or less than the artificial flaw size at that location.

Annex C (informative)

Records of manufacture

Note: *This Annex is not a mandatory part of this International Standard.*

Record of manufacture of compressed hydrogen vehicle fuel containers

Manufactured by ____

Located at ____

Certification Number or Symbol ____

Manufacturer's Number ____

Serial Numbers __________________________ to __________________________________inclusive

Container Type (check one): 1 ______ 2 ______ 3 ______ 4 ______

Size: ______ mm outside diameter by ______ mm overall length (excluding container appurtenances).

Marks stamped on the shoulder or on labels of the container are:

Manufacturer Name/Contact Information ____

Date of Manufacture____

Date of Removal from Service____

Number of Cycles (Category B only)____

"ISO 19881:xxxx-Hyyz"____

"MFP xx.x"____

Manufacturer Part Number and Serial Number____

"For Use Only With the Container Manufacturer's Approved Pressure Relief Devices and Valves"

"Container Service Life Ends After Use in a Single Vehicle – Container Transfer Between Vehicles is Prohibited"

Each container was made in compliance with all details of ISO 19881 in accordance with the specified type. Required records of test results are attached.

I hereby certify that all these containers proved satisfactory in every way and are in compliance with the requirements of ISO 19881.

Comments: ____

____

Inspection Agency ____

Inspector's Signature ____

Manufacturer's Signature ____

Place ____ Date _________

Record of chemical analysis of material
for metallic containers, liners, and bosses

Container Type (check one): 1 ______ 2 ______ 3 ______ 4 ______

Size: ______ mm outside diameter by ______ mm overall length (excluding container appurtenances).

Material Description ____

Steel

Test No.	Heat No.	Jominy Hardness (HRC)		Check Analysis Number	Containers Represented (Serial Nos.)	Chemical Analysis								
		first	last			C	P	S	Si	Mn	Cr	Mo	B	Al

Aluminum

Alloy Designation (Per Alum. Assoc.)	Containers Represented (Serial Nos.)	Chemical Analysis										
		Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Pb	Bi	Others	
												Ea.	Total

Inspection Agency ____

Inspector's Signature ____

Manufacturer's Signature ____

Place ____ Date ________________

Record of mechanical properties of material for metallic containers, liners, and bosses

Container Type (check one): 1 ______ 2 ______ 3 ______ 4 ______

Size: ______ mm outside diameter by ______ mm overall length (excluding container appurtenances).

Material Description

Tensile Specimen size: Width ______ mm by mm ______ gauge length.

Impact Specimen size: 10 mm deep by ______ mm wide. (Not applicable to Aluminum.)

Heat or Batch Code Number	Containers Represented (Serial Nos.)	Yield Strength at 0.2% Offset MPa(psig)	Tensile Strength MPa(psig)	Elongation (percent)

Charpy V-Notch Test		
Energy		Lateral Expansion
Average Value for 3 Specimens J/cm^2	Minimum Value for 1 Specimen J/cm^2	Range Value for 3 Specimens mm

Heat codes stamped into each container (yes or no)

Inspection Agency ____

Inspector's Signature ____

Manufacturer's Signature ____

Place ____ Date _________________

Record of physical and mechanical properties of material for nonmetallic liners

Container Type: 4, Numbered ______ to ______ inclusive.

Size: ______ mm (______ in) outside diameter by ______ mm (______ in) overall length (excluding container appurtenances).

Linear Material Description ____

Boss Material Description ____

Minimum Liner Thickness ____

Melt Temperature, ______ °C (______ °F)

Batch Code Number	Containers Represented Serial Nos.	Tensile Strength MPa (psig)	Elongation (percent)

Inspection Agency ____

Inspector's Signature ____

Manufacturer's Signature ____

Place ____ Date _________________

Record of composite analysis

Container Type (check one): 1 ______ 2 ______ 3 ______ 4 ______

Size: ______ mm (______ in) outside diameter by ______ mm (______ in) overall length (excluding container appurtenances).

Filament Type ____

Manufacturing Batch No. (units)	Tensile Strength MPa (psig)	Interlaminar Shear Strength MPa (psig)

Resin system description ____

	Type	Batch No(s).
Resin		
Curing Agent		
Accelerator		

Cure Temperature _____ °C (_____ °F)

Composite Properties ____

Inspection Agency ____

Inspector's Signature ____

Manufacturer's Signature ____

Place ____ Date ________________

Record of hydrostatic tests on containers

Container Type (check one): 1 ______ 2 ______ 3 ______ 4 ______

Numbered ____________ to ____________ inclusive.

Size: ______ mm (______ in) outside diameter by ______ mm (______ in) overall length (excluding container appurtenances).

Water Volume________________________ Minimum ________________________ Maximum

Manufacturer ____

Minimum prescribed test pressure, kPa (psig) ______ (______)

Autofrettage pressure, kPa ______ (______ psig) (Type 2 and Type 3 only)

Hydrostatic test								
S/N	Weights			Volume	Total Expansion cc (in^3)	Perm. Expansion cc (in^3)	Elastic Expansion	Ratio of Permanent to Total (%)

Cycling and burst tests			
Test Type	Serial No.	No. of Cycles	Burst Pressure, kPa (psig)
Cycling			
Hydro-static Burst			

Inspection Agency ____

Inspector's Signature ____

Manufacturer's Signature ____

Place ____ Date _________________

Annex D (informative)
Design qualification test rationale

Note: *This Annex is not a mandatory part of this International Standard.*

D.1 Category A and C design qualification tests

D.1.1 Ambient cycling test

The minimum number of pressure cycles without leakage (between 5 500 and 11 000) is established to verify resistance to leakage. 22 000 cycles provides additional assurance with respect to rupture. 22 000 empty-to-full fueling cycles is expected to be equivalent to over 10 million km of driving. Absence of rupture in hydraulic pressure cycling is demonstrated under the most stressful pressure cycling condition, which is the empty-to-full fill (from less than 2 MPa to 125 percent of the nominal working pressure). Note that a faster test time [lower number of pressure cycles until leakage occurs] could be achieved by cycling to higher pressures but that could elicit failure modes that could not occur in real world service.

See also the rationale in Clauses D.3, D.4 and D.5 for number of fill cycles.

D.1.2 Environmental test

The primary historical cause of rupture of high pressure vehicle containers (CNG containers), other than fire and physical damage, has been stress corrosion cracking – this cracking could occur during exposure to a combination of corrosive chemicals and pressurization. Stress corrosion cracking of on-road glass-composite wrapped containers exposed to battery acid was replicated by the proposed test protocol; other chemicals were added to the test protocol once the generic risk of chemical exposure was recognized.

D.1.3 Pendulum impact preconditioning

On-road impacts that degrade exterior structural strength and/or penetrate protective coatings (e.g. flying stone chips) is simulated by pendulum impact. The pendulum impact simulates a sharp stone measuring 25.4 mm in diameter travelling 100 km/hr.

D.1.4 Environmental fluids for exposure

In a study conducted by Battelle Memorial Institute (Columbus), “Categorization and Ranking of Potential NGV Environments and Their Influence”, a list of over 160 chemicals encountered in vehicular environments was grouped into five categories, and one from each was selected. The five categories were acid, base, hydrocarbon, ammonia, and surfactant.

(i) Fluids include fluids used on vehicles (battery acid and washer fluid), chemicals used on or near roadways (fertilizer nitrates and lye), and fluids used in fuelling stations (methanol and gasoline);

(ii) The primary historical cause of rupture of high pressure vehicle containers (CNG containers), other than fire and physical damage, has been stress corrosion rupture – rupture occurring after a combination of exposure to corrosive chemicals and pressurization;

(iii) Stress corrosion rupture of on-road glass-composite wrapped containers exposed to battery acid was replicated by the proposed test protocol; other chemicals were added to the test protocol once the generic risk of chemical exposure was recognized;

(iv) Penetration of coatings from impacts and expected on-road wear can degrade the function of protective coatings — recognized as a contributing risk factor for stress corrosion cracking (rupture); capability to manage that risk is therefore required (pendulum impact).

D.1.4.1 Pressure cycle and pressure hold

The 3 000 cycle number was based on the concept of 750 cycles per year = 4 years, which is the period between visual re-inspections, at which time environmental damage should be detected.

D.1.4.2 Acceptable results

Fuelling station over-pressurization constrained by fuelling station requirements to less than or equal to 150 percent of the nominal working pressure. (This requirement for fuelling stations shall be established within local codes/regulations for fuelling stations).

Laboratory data on static stress rupture used to define equivalent probability of stress rupture of composite strands after 4 minutes at 180 percent of the nominal working pressure as after 10 hours at 150 percent of the nominal working pressure as the worst case (SAE Technical Report 2009-01-0012). Fuelling stations are expected to provide over-pressure protection up to 150 percent of the nominal working pressure.

Testing at "end-of-life" provides assurance to survive fuelling station failure throughout service life.

D.1.5 Extreme temperature cycling test

The extreme temperature values have been defined by automotive OEM design conditions. Limiting the cold temperature test to 4 000 cycles, and the hot temperature test to 4 000 cycles, recognizes the fact that vehicle containers will not experience only a combination of extreme cold and extreme hot cycles during their lifetime. The 180 percent of the nominal working pressure residual burst pressure at end of cycle testing recognizes that a container at end of life must survive possible fueling station overpressure exceeding 150 percent of the nominal working pressure. Note that the temperature in the fluid of the container must be monitored, as temperature measured on the outside skin of a composite-reinforced container is insulated from the internal skin temperature.

D.1.6 Flaw tolerance test

Cuts characteristic of wear from mounting straps that can cause severe abrasion of protective coatings or composite reinforcement.

The 3 000 cycle number without leak or rupture was based on the concept of 750 cycles per year = 4 years, which is the period between visual re-inspections, at which time drop damage should be detected. Additional cycles are required to ensure the container would not fail during its intended service life, or if it did fail, it would only leak.

D.1.7 Drop test

The risk is primarily an aftermarket risk during vehicle repair where a new storage system, or an older system removed during vehicle service, is dropped from a fork lift during handling. The test procedure requires drops from several angles from a maximum utility forklift height. The test is designed to demonstrate that containers have the capability to survive representative pre-installation drop impacts.

D.1.8 Fire test

The fire test is designed to demonstrate that finished containers, complete with the fire protection system specified in the design, will prevent the rupture of the container when tested under the specified fire conditions. The rationale for the test conditions is provided in ECE/TRANS/180/Add.13, section (d) “Rationale for paragraphs 5.1.4. and 6.2.5. verification test for service-terminating performance in fire”.

Verification of performance under service-terminating conditions is designed to prevent rupture under conditions so severe that hydrogen containment cannot be maintained. Fire is the only service-terminating condition accounted for in design qualification.

A comprehensive examination of CNG container in-service failures during the past decade (SAE Technical Paper 2011-01-0251 [Scheffler, McClory et al., "Establishing Localized Fire Test Methods and Progressing Safety Standards for FCVs and Hydrogen Vehicles"]) showed that the majority of fire incidents occurred on storage systems that did not utilize properly designed pressure relief devices (PRDs), and the remainder resulted when PRDs did not respond to protect the container due to the lack of adequate heat exposure on the PRDs even though the localized fire was able to degrade the container wall and eventually cause the storage container to burst. The localized fire exposure has not been addressed in previous regulations or industry standards.

The fire test conditions were based on vehicle-level tests by the Japanese Automobile Research Institute (JARI) and US manufacturers. A summary of data is found in paper SAE Technical Paper 2011-01-0251. Key findings are as follows:

(a) About 40 per cent of the vehicle laboratory fires investigated resulted in conditions that could be categorized as a localized fire since the data indicates that a composite compressed gas container could have been locally degraded before conventional PRDs on end bosses (away from the local fire exposure) would have activated. (Note: A temperature of 300°C was selected as the temperature where the localized fire condition could start as thermal gravimetric analysis (TGA) indicates that container materials begin to degrade rapidly at this temperature);

(b) While vehicle laboratory fires often lasted 30-60 minutes, the period of localized fire degradation on the storage containers lasted less than 10 minutes;

(c) The average of the maximum temperature during the localized fire period was less than 570°C with peak temperatures reaching approximately between 600°C and 880°C in some cases;

(d) The rise in peak temperature near the end of the localized fire period often signaled the transition to an engulfing fire condition.

Based upon the above findings, the temperature profile in Figure 2 was adopted. The selection of 600°C as the minimum temperature for the localized fire hold period ensures that the average temperature and time of localized fire test exposure are consistent with test data. Thermocouples located 25 mm ± 10mm from the outside surface of the test article are used to control the heat input and confirm that the required temperature profile is met. In order to improve the response and controllability of the fire during testing (as well as reproducibility of results), the use of Liquefied Petroleum Gas (LPG) and wind guards are specified. Experience indicates the controllability of the LPG fire will be approximately ±100°C in outdoor situations, producing peak temperatures that also agree favourably with test results.

The proposed localized fire test set-up is based on preliminary work done by Transport Canada and the National Highway Traffic Safety Administration (NHTSA) in the United States of America, but the approach was expanded to allow the storage system to be qualified by either a generic installation test or a specific vehicle installation test. Differences between the two methods are as follows:

(a) The generic (non-vehicle specific) allows the localized fire test to apply to more than one vehicle but the mitigation devices (such as shields) need to be permanently affixed to the storage system and shall protect the entire system, not just the area exposed to the localized fire. The size for the generic localized fire test was selected to be 250 mm ± 50 mm longitudinally with a width covering the diameter of the container;

(b) The specific vehicle installation localized fire test would be customized to align with the actual fire exposure area and would include protective features from the vehicle. If the vehicle manufacturer elects to use the specific vehicle test approach, the direction and size of the localized fire exposure is adjusted to account for vehicle features such as openings in adjacent sheet metal for lightening holes and pass-throughs for wires and piping or holes formed by the melting of materials in the path of the fire. If such openings or holes are small, the size of the localized is reduced from the generic size to create a more challenging (and realistic) test.

D.1.9 Accelerated stress rupture test

Test was originally developed to determine if the applied stresses in an as-built composite reinforcement exceeded the stress ratios. It was found that sustained loading for 1 000 hours at high temperature could cause the stress rupture of glass fiber composite container designs that had otherwise failed in 2 years of active service.

The test is also used to simulate high temperature full-fill parking up to 25 years (prolonged exposure to high pressure). To avoid a performance test lasting for 25 years, a time-accelerated performance test using increased pressure developed using experimental material data on currently used metals and composites, and selecting the worst-case for stress rupture susceptibility, which is glass fibre reinforced composite. Use of laboratory data to establish the equivalence of testing for stress rupture at 100 percent of the nominal working pressure for 25 years and testing at 125 percent of the nominal working pressure for 1 000 hours (equal probability of failure from stress rupture) is described in SAE Technical Paper 2009-01-0012 (Sloane, "Rationale for Performance-based Validation Testing of Compressed Hydrogen Storage," 2009). Laboratory data on high pressure container composite strands – documentation of time-to-rupture as a function of static stress without exposure to corrosives – is summarized in Aerospace Corp Report No. ATR-92(2743)-1 (1991) and references therein.

(a) No formal data is available on parking duration per vehicle at different fill conditions. Examples of expected lengthy full fill occurrences include vehicles maintained by owners at near full fill conditions, abandoned vehicles and collectors' vehicles. Therefore, 25 years at full fill is taken as the test requirement;

(b) The testing is performed at +85°C because some composites exhibit a temperature-dependent fatigue rate (potentially associated with resin oxidation per J. Composite Materials 11, 79 (1977)). A temperature of +85°C is selected as the maximum potential exposure because an under-hood maximum temperature of +82°C has been measured within a dark-coloured vehicle parked outside on asphalt in direct sunlight in 50°C ambient conditions. Also, a compressed gas container, painted black, with no cover, in the box of a black pickup truck in direct sunlight in 49°C had maximum/average measured container skin surface temperatures of 87°C/70°C.

D.1.10 High strain rate impact test

Demonstrates impact and fragmentation resistance of a tank design, and is specifically retained to address the key differences of new materials technologies.

D.1.11 Permeation test

The permeation value for light duty vehicles results from a European Commission Network of Excellence "HySafe" activity to estimate an allowable hydrogen permeation rate for automotive legal requirements and standards [Adams, P., et al, "Allowable Hydrogen Permeation Rate For Automotive Applications", Deliverable D74 (insHyde) – Final with Corr. 1, June 15, 2009, HySafe]. The allowable permeation rate for hydrogen has been estimated based on a number of key assumptions:

- A structure should be safe regardless of the vehicle that enters it (although what vehicle can physically enter the structure is a limit in itself)
- The allowable rate should be set so the vehicle is safe throughout its intended service life
- The allowable rate should not rely on regulations affecting the structure to ensure safety, i.e. safety should be assured independent of the combination of vehicle and structure.

Accordingly, the specific assumptions used in the analysis included the following:

- Permeated hydrogen can be considered to disperse homogeneously.
- Worst credible natural ventilation rate for a domestic garage is 0.03 air changes/hr.
- Maximum permitted hydrogen concentration is 1% by volume, i.e. 25% LFL.
- Maximum long term material temperature is 55 ^{o}C.
- New container, with a factor of 2 to convert from the worst case end of life condition.
- For a test conducted at a temperature of 20 ^{o}C, a factor of 3.5 is used to convert from the maximum prolonged material temperature to the test temperature (factor 4.7 at 15 ^{o}C).

Based on the above assumptions, scenarios and methodology, the theoretical allowable permeation rates to give a hydrogen concentration less than 1% in air is 6.0 mL/hr/L water capacity at a 150 ^{0}C minimum testing temperature.

D.1.12 Boss torque test

A safety margin of 2 is applied to the manufacturer's recommended torque value for fittings attached to the metal end boss in plastic-lined containers.

D.1.13 Hydrogen gas cycling test

This is a performance test to evaluate the durability of the plastic liner in compressed hydrogen environments, including:

- Integrity of the plastic liner/end boss interface
- Excessive static electric discharges causing pinhole leaks
- Effects of permeation over time on porosity in the liner
- Effects of extreme temperatures generated with fast fills and discharges

D.1.14 Leak before break test

A potential failure mode in all-metal or metal-lined containers is the growth of a fatigue crack. The design must demonstrate that it will leak and not "break" when a fatigue crack grows through the metal wall. Pressure cycle testing is conducted at 150 percent of the nominal working pressure to maximize the aspect ratio of fatigue cracks that grow from defects on the liner surface. Pressure cycle testing at even higher pressures would increase the risk of generating failure mechanisms that would not occur in service. This test does not apply to Type 3 designs because the metal liner does not carry the majority of the wall stress, thus a through-wall fatigue crack in the liner could only result in a leak condition.

D.2 Category B design qualification tests

The rationale for Category B container tests are detailed in the ECE/TRANS/180/Add.13, Global technical regulation No. 13: Global technical regulation on hydrogen and fuel cell vehicles, Established in the Global Registry on 27 June 2013.

D.3 Category A container fill cycles

Category A containers are containers that are intended to be used in light duty and heavy duty land vehicle applications, regardless of the potential for further qualification to the UN GTR for fuel cell vehicles. The 750 cycles per year is based on the extreme condition of assuming 2 empty-to-full fuelings per day for continual full-day service. Transit authorities have required up to 25 years of life x 750 cycles = 18 750 cycles total. The robustness of this specification is assured by recognition that 18 750 cycles x 200 driving miles/fueling cycle exceeds 3.5 million miles driven.

D.4 Category B container fill cycles

Category B containers are containers that are intended to be further qualified in accordance with the UN GTR for fuel cell vehicles with a gross vehicle mass of 4 536 kg or less. Pressure cycles are greater than or equal to 5 500 and less than or equal to 11 000.

The differences in the anticipated maximum number of fuelings are primarily associated with high usage commercial taxi applications, which can be subjected to very different operating constraints in different regulatory jurisdictions. For example:

a) Vehicle Fleet Odometer Data (including taxis): Sierra Research Report No. SR2004-09-04 for the California Air Resource Board (2004) reported on vehicle lifetime distance traveled by scrapped California vehicles, which all showed lifetime distances traveled below 560 000 km (350 000 mi). Based on these figures and 320 - 480 km (200 - 300 mi) driven per full fueling, the maximum number of lifetime empty-to-full fuelings can be estimated as 1 200 – 1 800.

b) Vehicle Fleet Odometer Data (including taxis): Transport Canada reported that required emissions testing in British Columbia, Canada, in 2009 showed the 5 most extreme usage vehicles had odometer readings in the 800 000 – 1 000 000 km (500 000 – 600 000 mi) range. Using the reported model year for each of these vehicles, this corresponds to less than 300 full fuelings per year, or less than 1 full fueling per day. Based on these figures and 320 - 480 km (200 - 300 mi) driven per full fueling, the maximum number of empty-to-full fuelings can be estimated as 1 650 – 3 100.

c) Taxi Usage (Shifts/Day & Days/Week) Data: The New York City (NYC) Taxicab Fact Book (Schaller Consulting, 2006) reports extreme usage of 320 km (200 mi) in a shift and a maximum service life of 5 years. Less than 10% of vehicles remain in service as long as 5 years. The average mileage per year is 72 000 for vehicles operating 2 shifts per day and 7 days per week.

d) There is no record of any vehicle remaining in high usage through-out the full 5 year service life. However, if a vehicle were projected to have fueled as often as 1.5 - 2 times per day and to have remained in service for the maximum 5-year NYC taxi service life, the maximum number of fuelings during the taxi service life would be 2 750 – 3 600 fuelings.

e) Taxi Usage (Shifts/Day & Days/Week) Data: Transport Canada reported a survey of taxis operating in Toronto and Ottawa that showed common high usage of 20 hours per day, 7 days per week with daily driving distances of 540 – 720 km (335 – 450 mi). Vehicle odometer readings were not reported. In the extreme worst-case, it might be projected that if a vehicle could remain at this high level of usage for 7 years (the maximum reported taxi service life); then a maximum extreme driving distance of 1 400 000 – 1 900 000 km (870 000 – 1 200 000 mi) is projected. Based on 320 - 480 km (200 - 300 mi) driven per full fueling, the projected full-usage 15-year number of full fuelings could be 2 900 – 6 000.

Consistent with these extreme usage projections, the minimum number of full pressure hydraulic qualification test cycles for hydrogen storage systems is set at 5,500. The upper limit on the number of full-fill pressure cycles is set at 11,000, which corresponds to a vehicle that remains in the high usage service of 2 full fueling per day for an entire service life of 15 years, providing a lifetime vehicle mileage of 3.5 – 5.3 million km (2.2 – 3.3 million miles).

a)Personal Vehicles -- Number of Fueling/De-fueling cycles for verification test

The number of fueling cycles that a hydrogen storage system must be capable of performing requires consideration of two scenarios of risk:

i) Expected Service: the worst-case fueling exposure for a typical vehicle is taken as a lifetime consisting of the most stressful fuelings - fuelings from <2MPa to 125 percent of the nominal working pressure, which causes the maximum pressure and temperature change.

   a. The maximum number of empty-to-full fuelings during expected service is given by: (expected lifetime vehicle range) / (expected driving range per full fill)

   b. Expected vehicle lifetime range is taken to be 250 000.

   c. Expected vehicle range per full fueling is taken to be 483km based on 2006-2007 market survey (Nissan, Daimler, Chrysler, General Motors, Ford, Honda, Toyota)

d. Therefore, the expected number of full fuelings in the worst-case (only full fuelings in vehicle lifetime) is taken to be 500 (approximately 250 000/483).

e. Since the stress of full fuelings exceeds the stress of partial fuelings, the design verification test provides a significant margin of additional robustness.

ii) Extended Durability: extreme usage -- where the vehicle sustains an extreme number of fuelings.

a. A higher than expected number of fuelings occurs if: 1) the vehicle lifetime mileage is higher than expected, 2) the vehicle range per full fill is lower than expected, and/or 3) the average vehicle fueling is less than a full fill.

b. The high-frequency extreme number of partial fuelings is given by: (extreme-usage lifetime vehicle range) / (minimal vehicle range per full fill) / (minimal lifetime average fill volume fraction).

c. The minimal lifetime average fill volume fraction is taken as 0.33. Reliable statistics on current fill volume fraction are not available; statistics for hydrogen-fueled vehicles will be influenced by the availability of hydrogen fueling stations. The qualification test specification is based on the assumption that a lifetime of fuelings needing <33% of fuel capacity provides a high-frequency extreme associated with a lifetime average of fuelings on intervals of 112 – 160 km traveled.

d. Extreme-usage lifetime vehicle range is taken as 590 000 km. Sierra Research Report No. SR2004-09-04 for the California Air Resource Board (2004) on vehicle lifetime mileage showed all scrapped vehicles had mileage below 563 500 km (the 3-sigma value, the 99.8th percentile, was 418 000 km; the 6-sigma value was 590 000 km.

e. Minimal vehicle range per full fill is taken as 322 km. At present all on-road vehicles produced by high volume vehicle manufacturers have a vehicle range per full fill greater than 500 km.

f. Therefore, the extreme number of fuelings is taken as 5 500 = 3 x 590 000/322.

g. Robustness (safety margin) of extended durability design-qualification requirement.

iii) A vehicle with a modest driving range of 322 km per full fueling would have to be driven over 1.6 million km to require 5 500 empty-to-full fuelings.

iv) Low-volume partial fills cause markedly lower swings in temperature and pressure, and consequently markedly lower stresses than empty-to-full fill stresses. Comprehensive data is not available (stresses an order of magnitude lower than empty-to-full fuelings have been seen). Therefore, conducting the high frequency fueling pressure cycle tests with empty-to-full fueling pressure swings provides a margin of robustness potentially on the order of x 10.

D.5 Category C container fill cycles

Category C containers are containers that are intended to be used on hydrogen powered industrial trucks. The 1 125 cycles per year is based on the extreme condition of assuming 3 empty-to-full fuelings per day for continual full-day service, which is a very realistic possibility for industrial truck applications.