FINAL DRAFT

INTERNATIONAL STANDARD

ISO/FDIS 19881

ISO/TC **197**

Secretariat: SCC

Voting begins on: **2018-07-27**

Voting terminates on: **2018-09-21**

Gaseous hydrogen — Land vehicle fuel containers

Hydrogène gazeux — Réservoirs de carburant pour véhicules terrestres

Reference number
ISO/FDIS 19881:2018(E)

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee TC 197, *Hydrogen technologies*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The purpose of this document is to promote the implementation of hydrogen powered land vehicles through the creation of performance based testing requirements for compressed hydrogen fuel containers. The successful commercialization of hydrogen land vehicle technologies requires standards pertaining to fueling stations, vehicle fuel system components and the global homologation of standards requirements for technologies with the same end use. This will allow manufacturers to achieve economies of scale in production through the ability to manufacture one product for global use.

This document is based on the CSA Standard ANSI/HGV 2-2014.

Gaseous hydrogen — Land vehicle fuel containers

1 Scope

This document 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 land vehicle operation. These containers

a) are permanently attached to the vehicle,

b) have a capacity of up to 1 000 l water capacity, and

c) have a nominal working pressure that does not exceed 70 MPa.

The scope of this document is limited to fuel tanks containing fuel cell grade hydrogen according to ISO 14687 for fuel cell land vehicles and Grade A or better hydrogen as per ISO 14687 for internal combustion engine land vehicles. This document also contains requirements for hydrogen fuel tanks acceptable for use on-board light duty vehicles, heavy duty vehicles and industrial powered trucks such as forklifts and other material handling vehicles.

2 Normative references

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

ISO 148-1, *Metallic materials — Charpy pendulum impact test — Part 1: Test method*

ISO 306, *Plastics — Thermoplastic Materials — Determination of Vicat Softening Temperature (VST)*

ISO 7866:2012, *Gas cylinders — Refillable seamless aluminium alloy gas cylinders — Design, construction and testing*

ISO 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*

ISO 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*

ISO 11439:2013, *Gas cylinders — High pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles*

ISO 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*

ISO 19882[1)], *Gaseous hydrogen — Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers*

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

ASTM D2344/D2344M-00, *Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates*

ASTM D3359, *Standard Test Methods for Measuring Adhesion by Tape Test*

1) Under preparation.

ASTM D3418, *Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry*

ASTM D4138, *Standard Practices for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive, Cross Sectioning Means*

ASTM D4814, *Standard Specification for Automotive Spark-Ignition Engine Fuel*

ASTM D7091, *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*

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

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

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

CGA C-1-2009, *Methods for Pressure Testing Compressed Gas Cylinders*

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

SAE J2579:2013, *Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles*

SAE J2601, *Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles*

UN GTR No. 13, *UN Global Technical Regulation on Hydrogen and Fuel Cell Vehicles*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
autofrettage
pressure application procedure, used in manufacturing composite containers with metal *liners* (3.14), which strains the *liner* (3.14) past its yield point sufficiently to cause permanent plastic deformation that results in the *liner* (3.14) having residual compressive stresses and the fibers having residual tensile stresses at zero internal pressure

3.2
burst pressure
highest pressure reached in a container during a burst test

3.3
composite
filament and resin system

3.4
container category
unique class of containers that are intended for a specific usage

3.4.1
Category A
class of 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 No. 13 for hydrogen and fuel cell vehicles

3.4.2
Category B
class of *Type 4* (3.5.4) containers that are intended to be further qualified in accordance with the UN GTR No. 13 for hydrogen and fuel cell vehicles with a gross vehicle mass of 4 536 kg or less

3.4.3
Category C
class of containers that are intended to be used on hydrogen powered industrial trucks

3.5 Container type

3.5.1
Type 1
metal container

3.5.2
Type 2
container which contains a metal *liner* (3.14) reinforced with a resin impregnated continuous filament (hoop-wrapped)

Note 1 to entry: See 3.11.

3.5.3
Type 3
container which contains a metal *liner* (3.14) reinforced with a resin impregnated continuous filament (fully-wrapped)

Note 1 to entry: See 3.10.

3.5.4
Type 4
container which contains a resin impregnated continuous filament with a nonmetallic *liner* (3.14) (all composite)

Note 1 to entry: See 3.3.

3.6
design family
group of containers consisting of one fully qualified design and variations on that design that comply with Table 6

3.7
destroyed
in a state of alteration which makes a container physically unusable for its purpose

3.8
dry hydrogen
hydrogen which meets or exceeds the quality level in ISO 14687

3.9
fold
place where two material flows meet in such a manner as to create a sharp visual groove

3.10
full-wrapped
reinforced by a *composite* (3.3) material applied over the entire *liner* (3.14) including the domes

3.11
hoop-wrapped
reinforced by a *composite* (3.3) material applied in a substantially circumferential pattern over the cylindrical portion of the *liner* (3.14) so that the filament does not transmit any significant stresses in a direction parallel to the container longitudinal axis

3.12
leakage
release of contents through a defect or crack

3.13
leak test gas
gas for testing leaks that consists of *dry hydrogen* (3.8), dry helium or blends that contain these gases at a detectable level

Note 1 to entry: Use leak test gas in 9.3.

3.14
liner
inner gas tight container or gas container to which the overwrap is applied

3.15
maximum fueling pressure
MFP
maximum pressure applied to a compressed system during fueling

Note 1 to entry: The maximum fueling pressure is 125 % of the *nominal working pressure* (3.18).

3.16
minimum required burst pressure
minimum *burst pressure* (3.2) that is to be met during a burst test and which is needed to demonstrate the required *stress ratio* (3.26)

3.17
normal cubic centimeter
Ncc ()
dry gas that occupies a volume of 1 cm^3 at a temperature of 273,15 K (0 °C) and an absolute pressure of 101,325 kPa (1 atm)

3.18
nominal working pressure
container pressure, as specified by the container manufacturer, at a uniform gas temperature of 15 °C and full gas content

3.19
permanently attached
intended to remain fixed to a particular vehicle for the lifetime of the container or vehicle, whichever comes first

3.20
permeation
diffusion of the gaseous contents to the atmosphere at a molecular level, by means of pores or molecular gaps

3.21 Pressures

3.21.1
autofrettage pressure
pressure to which a container is taken with the intent of yielding the *liner* (3.14) or inner surface of the container

Note 1 to entry: The autofrettage operation is considered to be part of the manufacturing operation and is conducted prior to proof testing.

3.21.2
fill pressure
pressure attained at the actual time of filling

Note 1 to entry: 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 % of the *nominal working pressure* (3.18).

3.21.3
hydrostatic pressure
pressure to which a container is taken during acceptance testing

Note 1 to entry: See 17.3.5.

3.22
pressure relief device
PRD
device that, when activated under specified performance conditions, is used to vent the container contents

3.23
rejectable damage
damage as outlined in ISO 19078 or CGA C-6.4 and in agreement with the container manufacturer's recommendations

3.24
rupture
sudden and unstable damage propagation in the structural components of the container resulting in loss of contents

3.25
settled temperature
uniform gas temperature after any change in the temperature caused by filling has dissipated

3.26
stress ratio
minimum ultimate strength of the fiber, as determined in pressure container burst tests, divided by the stress in the fiber at the *nominal working pressure* (3.18)

4 Service conditions

4.1 General

4.1.1 Standard service conditions

The standard service conditions specified herein 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, UN GTR No. 13, or other equivalent standards.

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 No. 13 for hydrogen and 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 No. 13 for hydrogen and 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, Category B and Category C containers are intended to provide a sufficient level of safety for the intended application, but test methods and records are different.

4.1.3 Service life

The service life for the containers shall be specified by the container manufacturer. The specified life shall not be less than 10 years or greater than 25 years as defined in 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 according to Clause 15. Guidance on periodic inspection is included in Annex A.

4.2 Pressures

4.2.1 Nominal working pressures

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

a) “H25” — 25 MPa;

b) “H35” — 35 MPa;

c) “H50” — 50 MPa;

d) “H70” — 70 MPa.

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) Normally up to 125 % of the nominal working pressure immediately after filling, regardless of the gas temperature, and infrequently up to 150 % under dispenser fault conditions.

4.3 Maximum number of filling cycles

Containers are designed to be filled to pressures not exceeding the requirements of 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 1 Refer to D.3, D.4, and D.5 for the rationale on container fill cycles.

NOTE 2 Containers are expected to be removed from service when the service life used in the design qualification has expired, consistent with the labelling requirements in Clause 15.

4.4 Temperature range

4.4.1 Settled gas temperatures

Settled temperature of the gas in containers may vary from −40 °C to 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 4.4.1. Containers qualified to meet this document 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 °C ± 5 °C.

4.5 Gas composition

Containers made according to this document are designed to be used with hydrogen fuel complying with ISO 14687 or SAE J2719. Containers made according to this document can also be used for hydrogen road vehicles with hydrogen fuel (Type I Grade A) complying with ISO 14687.

4.6 External surfaces

Container external surfaces shall be designed to be resistant to environmental conditions outlined in 17.3.3.

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.

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 document 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 original manufacturer's design specifications are not authorized.

Table 1 summarizes specific material tests that are required herein subsequently.

Table 1 — Material tests

Material tests	Clause	Material type	Container 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	9.3	Nonmetallic liner welds				•

6.2 Material requirements

Materials normally in contact with hydrogen shall be determined to be acceptable in hydrogen service, with the 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 container manufacturer to carefully screen materials of construction for their intended use. The 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 and/or acceptance criteria in hydrogen environments can be found in the ISO 11114 series, 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 J2579:2013, Appendix B.

Nonmetallic materials normally in contact with hydrogen shall be verified 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 container 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 a 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. The container manufacturer shall demonstrate that exposure to high-pressure hydrogen under the service conditions provided in Clause 4 does 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 content in all cases, and

b) nickel, chromium, molybdenum, boron, vanadium or any other elements that are deliberately added.

Aluminum alloys shall be quoted in line with the Aluminum Association practice for a given alloy system. The impurity limit for bismuth in any aluminum alloy shall not exceed 0,003 %. Aluminum alloys 6351 and 6082 shall not be used.

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 the test piece	(mm)	5,0 to 7,5	7,5 to 10,0
Impact strength	(J/cm^2)	35	40

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 % of the average value.

6.3.3 Tensile tests for metals

Tensile strength methods shall be according to the Test Methods of ASTM E8/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 alloys

The resistance to SLC shall be determined in accordance with ISO 7866:2012, Annex B and shall meet the requirements therein.

6.3.5 Corrosion tests for aluminum alloys

Corrosion tests for aluminum alloys shall be carried out in accordance with ISO 7866:2012, Annex A and shall meet the requirements therein.

6.4 Ultraviolet resistance of external coatings

Protective coatings required to meet 17.3.3 shall be evaluated for resistance to ultraviolet effects using a minimum 1 000 h exposure using a UVA 340 lamp in accordance with ASTM G154. Evidence of blistering, cracking, chalking or softening shall be a cause for rejection.

6.5 Fibers

Structural reinforcing filament material types shall be glass fiber, aramid fiber, carbon fiber or mixtures or hybrids thereof. 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 h 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.

NOTE There is safe container operation experience at Tg at least 20 °C above the maximum container temperature. At temperatures less than this value, viscous flow phenomena can have an effect, resulting in stress concentration and damage accumulation in the laminate.

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 17.3.8 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 −50 °C.

The softening temperature shall be sufficiently high to meet the service conditions specified in Clause 4. The container manufacturer shall establish the suitable value for the softening temperature and the 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 6.2, 6.3.1, 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 document.

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 document are met.

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

NOTE The analysis of Type 4 cylinders is relatively straightforward because the composite stresses are linear with pressure. The analysis of Type 2 and Type 3 cylinders is more complicated because of the non-linear behaviour of the metal liner, specifically as it is subjected to the autofrettage pressure. It is critical that stress ratio requirements are met to ensure high reliability in regards to stress rupture (see ISO/TR 13086-1 for additional information). Stress ratios are not an issue with Type 1 containers, as they do not have composite reinforcement.

A thick liner, in combination with a high autofrettage pressure, can result in sufficient pre-stress on the composite such that the fiber is loaded in excess of the allowed stress ratio.

Type 2 designs are not likely to experience an excessive pre-stress condition if the liner burst pressure does not exceed 150 % of the nominal container working pressure, and the autofrettage pressure does not exceed 165 % of the nominal working pressure.

Type 3 designs are not likely to experience an excessive pre-stress condition if the liner burst pressure does not exceed 30 % of the nominal container working pressure, and the autofrettage pressure does not exceed 165 % of the nominal working pressure.

It is important to accurately calculate stresses in order to ensure stress ratio requirements are met, particularly when the liner thickness or autofrettage pressure exceeds the values noted above.

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

NOTE For guidance on the calculation of stress ratio values, see ISO/TR 13086-1.

7.3.3 Modified stress ratio test

At the option of the container 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 the 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 12.5 or 17.3.5. Acceptable alternative combinations of hold times and pressures are as follows:

a) 1 min at 250 % of the nominal working pressure;

b) 1 h at 225 % of the 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 %, 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 a hybrid construction may be verified by the 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 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;

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

7.4 External loads on containers

Containers with greater than 450 l 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 includes bending and torsional stresses.

8 Threaded openings

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

Threads shall be clean cut, even and to gauge.

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

9 Manufacture

9.1 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 container 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.

9.2 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.

9.3 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 nonmetallic 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 container manufacturer. Tensile tests of liner weld specimens shall be conducted on samples manufactured at the extreme limits of the process within which the container manufacturer controls the weld process.

Tensile testing of liner weld specimens shall be conducted during qualification of the weld process at −40 °C, at an ambient temperature and at 85 °C.

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

9.4 Composite containers with metallic liners

The container shall be fabricated from a metal liner overwrapped with resin impregnated continuous filament windings or using an equivalent method. 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.

9.5 Composite containers with nonmetallic liners

Type 4 composite containers shall be fabricated from a nonmetallic liner overwrapped with resin impregnated continuous filament windings or using an equivalent method. 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 as such that if, when pressurized, the liner is susceptible to creep and flow, no leakage will occur during the prescribed lifetime.

The softening temperature for the liner may be exceeded during processing if the qualification testing verifies that the completed container passes all required tests.

9.6 Brazing

Brazing for any purpose whatsoever shall not be permitted.

9.7 Welding

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

9.8 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 inspected using non-destructive examination (NDE). 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.

9.9 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, provided 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 3 or Table 4, as applicable.

9.10 Batch definitions

9.10.1 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 the length up to ±50 %.

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 the length up to ±50 %.

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 the length up to ±50 %.

9.10.2 The batch size shall be determined and managed under the container manufacturer’s quality control system.

9.11 Design qualification tests

Prior to initialling the in service usage of any specific container design, qualification tests as prescribed in Clause 17, shall meet all applicable requirements.

10 Production tests and examinations

10.1 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 container manufacturer's specified limits;

NOTE Guidance for the determination of the container manufacturer's specified limits can be found in Annex B.

b) verification through visual or non-destructive examination that nonmetallic liners are free of flaws exceeding the container manufacturer's specified limits (see 9.3 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 the 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 the coating quality (if required);

f) verification of markings;

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.

Table 2 — Production verification requirements (See 10.1)

Production verification requirement(s):	Provision	Container type			
		1	2	3	4
Dimensions	10.1 (c)	X	X	X	X
Flaws	10.1 (a) and (b)	X	X	X	X
Strength (heat treatment) of metal containers, metal liners and metal bosses	10.1 (g)	X	X	X	X
Hydrostatic test	10.2	X	X	X	X
Leak test	10.3	a	a	a	X
Coatings (where required)	10.1(e)	X	X	X	X
Surface finish	10.1(d)	X	X	X	X
End closing by forming (Steel)	9.8	X	X	X	
Markings	10.1(f)	X	X	X	X

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

10.2 Hydrostatic test

Each finished container shall be hydrostatically tested to at least 150 % of the nominal working pressure. Measuring systems for pressure and expansion shall meet the accuracy and periodic calibration requirements of CGA C-1-2009, or ISO 11439:2013, A.11. Pressure shall be maintained for

30 s 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 0,69 MPa minimum.

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

10.3 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 shall not be considered to be leakage.

a) Containers shall be thoroughly dried and then pressurized to the nominal working pressure with a detectable gas or gas mixture.

b) Containers shall be placed in an enclosure to permit the detection of any leaks.

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

Extreme care should be taken not to create explosive mixtures of gases within the container or test area (enclosure) when using combustible gases. Precautions should be taken in consideration of the potential for the release of combustible gases.

11 Batch tests

11.1 General

Batch testing shall be conducted on finished containers or liners that are representative of the 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 document, all results shall be documented.

When the test results fail to meet the 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 % 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.

11.2 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 in 6.3.3.

c) For steel containers and liners, three impact tests in accordance with the method specified in 6.3.2.

11.3 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:

   1) ASTM D7091;

2) ASTM D4138.

b) Containers that do not meet the container 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 container manufacturer's approved procedure.

Where the coating fails to meet the requirements, the batch shall be 100 % 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.

11.4 Burst test

11.4.1 Batch burst test

One container selected from each batch shall be hydrostatically pressurized to burst in accordance with the test procedure described in 17.3.5.2. 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 11.5 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.

11.4.2 Periodic burst test

11.4.2.1 The requirement in 11.4.1 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 11.4.1. If the container from any batch fails to meet the minimum required burst pressure, the batch shall be rejected.

11.4.2.2 If five sequential batches pass the burst test, 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, a container from the next batch of containers manufactured shall be burst-tested.

11.4.2.3 If a container fails to meet the minimum burst test requirement, 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.

11.5 Cycle test

11.5.1 Batch cycle test

One container selected from each batch shall be pressure cycle tested in accordance with the following.

11.5.2 Periodic pressure cycling test

11.5.2.1 The container shall be pressure cycle tested 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 MPa ± 1 MPa and 125 % of the 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. The maximum pressurization rate shall be 2,75 MPa per second.

c) Leakage may occur in any region of the container. The number of cycles attained before failure shall meet or exceed the number specified above; otherwise, the batch shall be rejected.

11.5.2.2 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.

11.5.2.3 If five sequential batches pass the cycling test, 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, a container from the next batch of containers manufactured shall be cycle tested.

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

12 Rejected containers and liners

12.1 Physical test

In the event of failure to meet the physical test requirements, retesting or reheat treatment and retesting shall be authorized as follows to the satisfaction of the Inspector.

a) If there is evidence of a fault in carrying out a test or an error of measurement, a further test shall be performed. If the result of this test is satisfactory, the first test shall be ignored.

b) If the test has been carried out in a satisfactory manner, the cause of test failure shall be identified.

   1) If the failure is considered to be due to the heat treatment applied, the manufacturer may subject all the cylinders implicated by the failure to a further heat treatment, e.g. if the failure is in a test representing the prototype or batch cylinders. A test failure shall require reheat treatment of all the represented cylinders prior to retesting. One additional heat treatment shall be allowed for aluminum and two additional heat treatments are allowed for steel. Additional heat treatments require the validation by material properties testing (6.3.2 and 6.3.3) for steels.

      This reheat treatment shall consist of either re-tempering or a complete reheat treatment.

      Whenever cylinders are reheat treated, the minimum guaranteed wall thickness shall be maintained.

      Only the relevant prototype or batch tests needed to prove the acceptability of the new batch shall be performed again. If one or more tests prove even partially unsatisfactory, all cylinders of the batch shall be rejected.

   2) If the failure is due to a cause other than the heat treatment applied, all cylinders with imperfections shall be either rejected or repaired such that the repaired cylinders pass the test(s) required for the repair. They shall then be re-instated as part of the original batch.

12.2 Leak test

Containers with leaks not meeting the requirements of 10.3 shall not be placed in service.

12.3 Hydrostatic test

Rejected containers not meeting the requirements of 10.2 shall not be placed in service.

12.4 Cycle test

Containers from rejected batches (see 11.5) shall not be placed in service.

12.5 Burst test

Containers from rejected batches (see 11.4) shall not be placed in service.

13 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 17.3.8.

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

14 Records of manufacture

The container 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 C.

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.

15 Marking and dispatch

15.1 Markings

15.1.1 General

On each container, the container manufacturer shall provide clear permanent markings. Markings may be included on either a single label or divided among multiple labels. All labels should be located such that they are not obscured by mounting brackets. Label position should be agreed with the vehicle manufacturer to assist reading when installed in the vehicle. Duplicate labels are allowed.

15.1.2 Marking information

Each container meeting the requirements of this document shall be marked as follows:

a) Mandatory information:

   1) name and contact information of the container manufacturer;

   2) date of manufacture;

3) date of removal from service;

4) number of cycles used in the test program (Category B containers only);

5) ISO 19881:xxxx-Hyyz (where "xxxx" denotes the year of the standard according to which the container is designed, "yy" denotes the nominal working pressure designation identified in 4.2.1, and "z" denotes the A, B or C designation identified in 4.3);

6) MFP xx.x (where "xx.x" denotes the maximum fueling pressure);

7) container manufacturer's part number and serial number;

8) the statement "For Use Only with the Container Manufacturer's Approved Pressure Relief Devices and Valves";

9) the statement "Container Service Life Ends after Use in a Single Vehicle — Container Transfer between Vehicles Is Prohibited";

10) the statement "Mounting Shall Be in Accordance with the Container Manufacturer's Instructions."

b) Non-mandatory information can be added but it shall be presented in such a form so as not to be confused with the 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.

15.2 Dispatch inspection

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

16 Quality assurance

Tests and examinations performed to demonstrate compliance shall be conducted using instruments calibrated before being put into service and thereafter according to an established programme.

17 Design qualification tests

17.1 General

Qualification testing shall be conducted on finished containers that are representative of the 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 an authorized inspection body, where necessary.

17.2 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 17.3.

Category B design qualification requirements are prescribed in Table 4, using procedures found in 17.3 and 17.5.

Category C design qualification requirements are prescribed in Table 3, using procedures found in 17.3 and with the conditions and limitations found in 17.6.

The 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 Inspector or demonstrated by the 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 s 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 the pressure verification was performed.

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

Caution shall be taken to confirm that the specified test temperature and test pressure are maintained. Unless stated otherwise, the tests specified herein shall be conducted with the following tolerances on specified temperatures and pressures:

a) −40 °C (0,−5) °C;

b) +85 °C (0,−5) °C ;

c) P_{max} +2,0 MPa.

Temperatures and pressures may be exceeded if specified by the manufacturer.

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

Table 3 — Test requirements for Category A and C containers (See 9.9 and 17.2.)

Clause	Test name	Type 1	Type 2	Type 3	Type 4
17.3.2	Ambient cycling test	•	•	•	•
17.3.3	Environmental test		•	•	•
17.3.4	Extreme temperature cycling test		•	•	•
17.3.5	Hydrostatic burst test	•	•	•	•
17.3.6	Flaw tolerance test	•	•	•	•
17.3.7	Drop test		•	•	•
17.3.8	Fire test	•	•	•	•
17.3.9	Accelerated stress rupture test		•	•	•
17.3.10	High strain rate impact test	•	•	•	•
17.3.11	Permeation test				•
17.3.12	Boss torque test				•
17.3.13	Hydrogen gas cycling test	•	•	•	•
17.3.14	Leak before break test	•	•		

Table 4 — Test requirements for Category B containers (See 9.9 and 17.2.)

Clause	Test name
17.5.2	Ambient cycling test (per 17.3.2)
17.5.3	Hydrostatic burst test (per 17.3.5)
17.5.4	Container test for performance durability
17.3.8	Fire test
17.5.5	Container test for expected on-road performance

17.3 Category A, B and C: design qualification tests

17.3.1 Test requirements

Category A and C containers shall be subjected to the tests specified in 17.3. Category B containers shall be subjected to the tests specified in 17.3, as applicable.

17.3.2 Ambient cycling test

17.3.2.1 Sampling

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

17.3.2.2 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 MPa ± 1 MPa and 125 % of the nominal working pressure at a rate not greater than 10 cycles per minute for the following number of cycles:

   1) Category A containers: Number of cycles equivalent to 1 500 times the service life of the container in years.

   2) Category B containers: Number of cycles equivalent to 11 000, 15 000 or 22 000 cycles for a 15-year service life.

   3) Category C containers: Number of cycles equivalent to 2 250 times the service life of the container in years.

17.3.2.3 Acceptable results

a) Category A containers shall not leak before reaching a number of cycles equivalent to 750 times and shall not rupture before reaching 1 500 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, 7 500 or 11 000 cycles and shall not rupture before reaching 11 000, 15 000 or 22 000 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, and shall not rupture before reaching 2 250 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.

NOTE It is acceptable for the pressurizing fluid to rise above the ambient temperature as long as the temperature of the test chamber and the fluid do not exceed the maximum specified temperature of the container.

17.3.3 Environmental test

17.3.3.1 Sampling

One finished container including coating, if part of the design, shall be subjected to the environmental test.

17.3.3.2 Procedure

17.3.3.2.1 General

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

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.

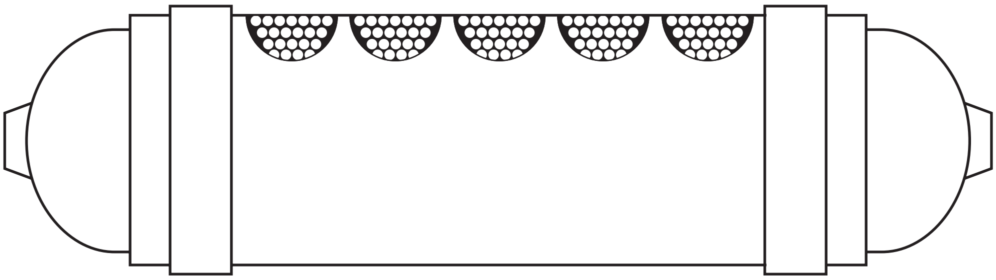


Figure 1 — Container orientation and layout of exposure areas (See 17.3.3.2.1 and 17.3.3.2.3)

17.3.3.2.2 Pendulum impact preconditioning

The impact body shall be of steel and have the shape of a pyramid with equilateral triangle faces at a 45° angle 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. 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 the impact of the pendulum body summit at the center of the area. The container shall be unpressurized during preconditioning.

17.3.3.2.3 Environmental fluids for exposure

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

a) sulfuric acid – 190 ml/l in water,

b) sodium hydroxide – 25 % solution by weight in water,

c) methanol/gasoline – 5 %/95 % concentration of M5 fuel meeting the requirements of ASTM D4814,

d) ammonium nitrate – 28 % by weight in water, and

e) windshield washer fluid (500 ml/l methanol in water).

When exposed, the test sample is oriented with the exposure area uppermost. A pad of glass wool approximately 0,5 mm thick and between 90 mm 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 immediately prior to the start of pressure cycling. Reapply the test fluid as needed to maintain the pad saturation.

17.3.3.2.4 Pressure cycle and pressure hold

Containers shall be hydraulically pressure cycled between 2 MPa ± 1 MPa and 125 % of the nominal working pressure for a total of 3 000 cycles. The maximum pressurization rate shall be 2,75 MPa per second. After pressure cycling, containers shall be pressurized to 125 % of the nominal working pressure and held at that pressure a minimum of 24 h and until the elapsed exposure time (pressure cycling and pressure hold) to the environmental fluids totals a minimum of 48 h.

17.3.3.2.5 Acceptable results

Following the above test sequence, the residual burst strength of the container shall be no less than 180 % of the nominal working pressure when tested in accordance with the hydrostatic burst test in 17.3.5.

17.3.4 Extreme temperature cycling test

17.3.4.1 Sampling

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

17.3.4.2 Procedure

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

a) Stabilize the container at 85 °C or higher.

b) Hydraulically pressure cycle between 2 MPa ± 1 MPa and 125 % of the nominal working pressure for 4 000 cycles for Category A containers and 4 500 cycles for Category C containers. 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 ambient conditions.

d) Stabilize the container at −40 °C or lower.

e) Hydraulically pressure cycle between 2 MPa ± 1 MPa and 80 % of the nominal working pressure for 4 000 cycles for Category A containers and 4 500 cycles for Category C containers. 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.

17.3.4.3 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 % of the nominal working pressure when tested in accordance with the hydrostatic burst test in 17.3.5.

17.3.5 Hydrostatic burst test

17.3.5.1 Sampling

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

17.3.5.2 Procedure

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

The rate of pressurization shall not exceed 1,4 MPa per second at pressures in excess of 150 % of the nominal working pressure. If the rate of pressurization at pressures in excess of 150 % of the nominal working pressure exceeds 0,35 MPa per second, either the container shall be placed schematically between the pressure source and the pressure measurement device or there shall be a 5 s hold at the minimum required burst pressure.

17.3.5.3 Acceptable results

The actual burst pressure shall be recorded.

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

17.3.6 Flaw tolerance test

17.3.6.1 Sampling

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

17.3.6.2 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 saw cuts in the longitudinal direction cut into the container sidewall. One flaw shall be minimum 25 mm long and minimum 0,42 mm deep and the other flaw shall be minimum 200 mm long and minimum 0,25 mm deep.

b) The flawed container shall then be pressure cycled, from 2 MPa ± 1 MPa and 125 % 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 minimum 25 mm long and minimum 1,25 mm deep and the other flaw shall be minimum 200 mm long and minimum 0,75 mm deep.

d) The flawed container shall then be pressure cycled, from 2 MPa ± 1 MPa and 125 % 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.

17.3.6.3 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.

17.3.7 Drop test

17.3.7.1 Sampling

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

17.3.7.2 Procedure

For Types 2, 3, and 4 containers only:

a) One or more finished containers shall be drop tested at the 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 J, 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° 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 MPa ± 1 MPa to 125 % 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.

c) For Category B containers the orientation of the container being dropped [per the requirement of 17.3.7.2 a)] is determined as follows:

   1) One or more additional container(s) shall be dropped in each of the orientations described. The drop orientations may be executed with a single container or as many as four containers may be used to accomplish the four drop orientations.

   2) If more than one container is used to execute all three drop specifications, those containers shall undergo pressure cycling according to 17.3.2 until either leakage or 22 000 cycles without leakage have occurred. Leakage shall not occur within the number of cycles (5 500, 7 500 or 11 000).

   3) The container used for further testing shall be identified as follows:

      i) If a single container was subjected to all four drop orientations, the container being dropped shall undergo further testing as specified;

      ii) If more than one container is used to execute the four drop orientations and if all containers reach 22 000 cycles without leakage, the orientation of the container being dropped is the 45° orientation, and that the container shall then undergo further testing as specified;

      iii) If more than one container is used to execute the four drop orientations and if any container does not reach 22 000 cycles without leakage, the new container shall be subjected to the drop orientation(s) that resulted in the lowest number of cycles to leakage and then undergo further testing as specified.

17.3.7.3 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.

17.3.8 Fire test

17.3.8.1 Sampling

One finished container shall be subjected to the fire test.

17.3.8.2 Procedure

17.3.8.2.1 General

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

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 can occur.

17.3.8.2.2 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, 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, 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 the nominal working pressure (±1 MPa), pressure compensated for the ambient test temperature, such that the proper mass of gas is contained, and placed horizontally with the container bottom approximately 100 mm above the fire source. The fire source shall initiate within a 250 mm ± 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.

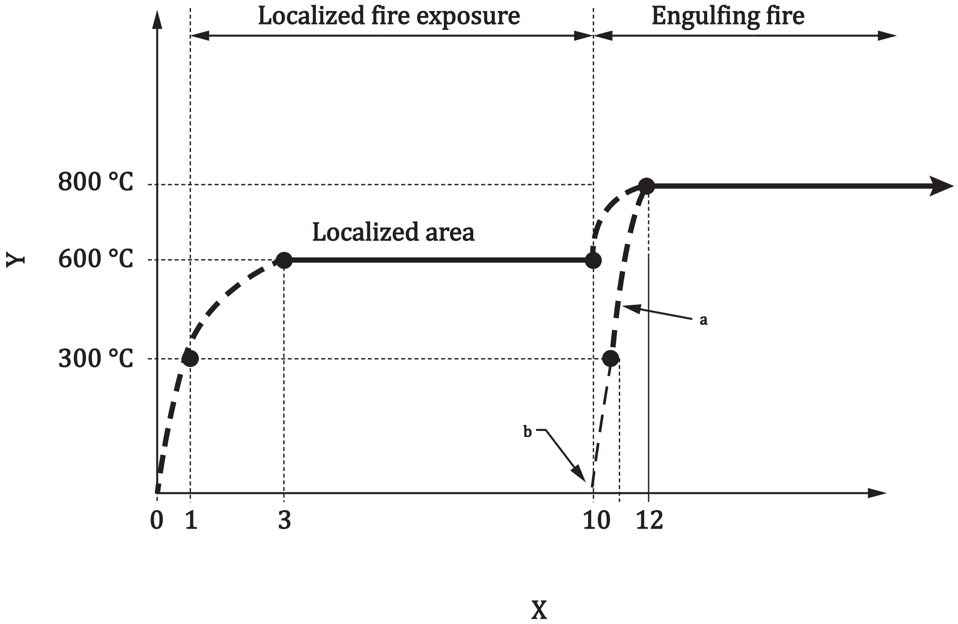
17.3.8.2.3 Fire source

The fire source shall consist of LPG burners configured to produce a uniform minimum temperature on the container defined as a moving 1 min average per thermocouple with 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 mm ± 10 mm from the outside surface of the container along its longitudinal axis. At the option of the container manufacturer or Inspector 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.

17.3.8.2.4 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 °C within 1 min of ignition, to at least 600 °C within 3 min of ignition, and a rolling average temperature of at least 600 °C shall be maintained for the next 7 min. Then, within the next 2 min interval, the temperature at the thermocouples in the fire source shall be increased to at least 800 °C and the fire source shall be extended to produce a rolling average temperature of at least 800 °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 min from the time of ignition.



Key

X minutes

Y Minimum temperature

a Engulfing region outside the localized area (burner ramp rate).

b Ignite the main burner.

Figure 2 — Minimum temperature during the fire test (See 17.3.8.2.4)

Table 5 — Fire test procedure description (See 17.3.8.2.4)

	Localized fire region	**Time period**	**Engulfing fire region (outside the localized fire region)**
Action	Ignite burners	0 to 1 min	No burner operation
Minimum temperature	Not specified		Not specified
Maximum temperature	Less than 900 °C		Not specified
Action	Increase the temperature and stabilize the fire for the start of localized fire exposure	1 to 3 min	No burner operation
Minimum temperature	Greater than 300 °C		Not specified
Maximum temperature	Less than 900 °C		Not specified
Action	Localized fire exposure continues	3 to 10 min	No burner operation
Minimum temperature	1 min rolling average greater than 600 °C		Not specified

Table 5 *(continued)*

	Localized fire region	Time period	Engulfing fire region (outside the localized fire region)
Maximum temperature	1 min rolling average less than 900 °C		Not specified
Action	Increase the temperature	10 to 11 min	Main burner ignited at 10 min
Minimum temperature	1 min rolling average greater than 600 °C		Not specified
Maximum temperature	1 min rolling average less than 1 100 °C		Less than 1 100 °C
Action	Increase the temperature and stabilize the fire for the start of engulfing fire exposure	11 to 12 min	Increase the temperature and stabilize the fire for the start of engulfing fire exposure
Minimum temperature	1 min rolling average greater than 600 °C		Greater than 300 °C
Maximum temperature	1 min rolling average less than 1 100 °C		Less than 1 100 °C
Action	Engulfing fire exposure continues 1 min rolling average	12 mins - end of test	Engulfing fire exposure continues 1 min rolling average
Minimum temperature	Greater than 800 °C		Greater than 800 °C
Maximum temperature	1 min rolling average less than 1 100 °C		1 min rolling average less than 1 100 °C

17.3.8.3 Acceptable results

The container shall be held at the 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 a 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 the 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 s or less during the test. Any failure to maintain specified temperature requirements during a test invalidates the result.

17.3.9 Accelerated stress rupture test

17.3.9.1 Sampling

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

17.3.9.2 Procedure

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

The container shall be hydrostatically pressurized to 125 % of the nominal working pressure (±1 MPa) while at a temperature of 85 °C. The container shall be held at this pressure and temperature for 1 000 h.

At the completion of the test the container shall be burst.

17.3.9.3 Acceptable results

The container shall exceed 75 % of the minimum burst pressure when tested in accordance with the hydrostatic burst test in 17.3.5.

The residual burst strength of the container shall be no less than 180 % of the nominal working pressure when tested in accordance with the hydrostatic burst test in 17.3.5.

17.3.10 High strain rate impact test

17.3.10.1 Sampling

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

17.3.10.2 Procedure

A container shall be pressurized to the nominal working pressure (±1 MPa) with nitrogen, helium or hydrogen and be impacted by either:

a) a 7,62 mm diameter armor-piercing projectile (specified as 7,62 mm × 51 mm 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°, a 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.

17.3.10.3 Acceptable results

The container shall not rupture.

17.3.11 Permeation test

17.3.11.1 Sampling

This test shall only be required on Type 4 containers.

One finished container shall be subjected to the permeation test.

17.3.11.2 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.

One container shall be filled with hydrogen to the nominal working pressure (±1 MPa), placed in an enclosed sealed container at 15 °C ± 5 °C. The test shall continue until the measured permeation reaches a steady state based on at least 3 consecutive readings separated by at least 12 h being within ±10 % of the previous reading.

17.3.11.3 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 document, the combination of permeation and leakage, if below the allowable permeation rate according to 17.3.11, constitutes compliance with the permeation requirements, and if above the allowable permeation rate according to 17.3.11, constitutes lack of compliance with the permeation requirements.

17.3.12 Boss torque test

17.3.12.1 Sampling

This test shall only be required on Type 4 containers.

One finished container shall be subjected to the boss torque test.

17.3.12.2 Procedure

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 10.3.

17.3.12.3 Acceptable results

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

17.3.13 Hydrogen gas cycling test

17.3.13.1 Sampling

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

17.3.13.2 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 MPa ± 1 MPa to 125 % of the 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 shall not be exceeded. The defueling rate shall be specified by the container manufacturer.

The first 500 cycles shall be conducted at the ambient temperature, followed by a static hold at 115 % of the nominal working pressure (±1 MPa) at 55 °C for a minimum of 30 h. The second 500 cycles shall be conducted with the container at an ambient temperature of −30 °C (250 cycles) and at 50 °C (250 cycles).

Subscale specimens may be used for this test with diameters reduced by as much as 20 % and lengths reduced by as much as 50 %.

17.3.13.3 Acceptable results

Following the completion of the test, the container shall meet the requirements of the leak test in 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.

17.3.14 Leak before break test

17.3.14.1 Sampling

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

17.3.14.2 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 MPa ± 1 MPa and 150 % of the nominal working pressure at a rate not to exceed 10 cycles per minute in accordance with 17.3.2.

17.3.14.3 Acceptable results

All containers shall either fail by leakage or exceed the maximum number of filling cycles for the design category.

17.4 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, the Inspector 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), the test result for the 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 17.4)

Test	Original design	Fiber material or manufacturer[a]	Resin system material or manufacturer	Liner or metal container material or manufacturer[k]	Dia. ≤20 % change[f]	Dia. >20 % change[f]	Service pressure ≤20 % change[f]	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 (17.3.2)	X	X	X[m]	X	X[m]	X	X[m]	X[m]	X[m]	X[m]			X[m]
Environmental test[c] (17.3.3)	X	X[d]	X[i]									X	
Extreme temperature cycling[c] (17.3.4)	X	X[d]	X[i]	X									
Hydrostatic burst test (17.3.5)	X	X	X[m]	X[n]	X[m]	X	X[m]	X[m]	X[m]	X[m]			X[m]
Flaw tolerance test[c] (17.3.6)	X		X[i]										
Drop test[c] (17.3.7)	X	X	X[i]	X[e]	X	X			X				
Fire test (17.3.8)	X	X	X[i]	X		X		X[b]	X		X[g]		
Accelerated stress rupture test[c] (17.3.9)	X	X	X										
High strain rate impact test (17.3.10)	X	X	X[i]	X[n]	X[h]	X		X[o]					
Permeation test[e] (17.3.11)	X			X									X[p]
Boss torque test (17.3.12)	X										X[l]		X

Table 6 *(continued)*

Test	Original design	Fiber material or manufacturer[a]	Resin system material or manufacturer	Liner or metal container material or manufacturer[k]	Dia. ≤20 % change[f]	Dia. >20 % change[f]	Service pressure ≤20 % change[f]	Length ≤50 % change	Length >50 % change	Integral mounting brackets & valve protection shrouds	Pressure relief devices or valves	External coating	Boss material or geometry
Hydrogen gas cycling test (17.3.13)	X			X									X[j]
Leak before break (17.3.14)	X	X		X		X							

[a] 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.

[b] Fire test is not required, provided safety relief devices or device configuration passed the required fire test on a container with equal or greater internal water volume.

[c] Test required only on composite reinforced containers.

[d] Not applicable to carbon fiber designs.

[e] Test required only for Type 4 containers.

[f] 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 increases proportionally).

[g] 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 % or when the pressure relief device is changed.

[h] Test required only if the diameter decreases.

[i] Test not required when resins of the same chemical and physical properties are substituted.

[j] Test required for Type 4 containers when the boss to liner interface is affected by design changes.

[k] 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.

[l] Only applicable for an increase in the valve torque.

[m] Only one unit required for design change; may be done as part of the batch test.

[n] Test not required for Type 4 containers.

[o] Test only required when the resulting container sidewall length is less than the diameter.

[p] Geometry only.

17.5 Category B: design qualification tests

17.5.1 General test requirements

Category B containers shall be subjected to the tests specified in 17.5.

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 in the UN GTR No. 13 or SAE J2579].

17.5.2 Ambient cycling test

Containers shall be subjected to the pressure cycling test specified in 17.3.2.

17.5.3 Hydrostatic burst test

Containers shall be subjected to the burst test specified in 17.3.5. The container manufacturer shall supply documentation (measurements and statistical analyses) that establishes the midpoint burst pressure of new containers.

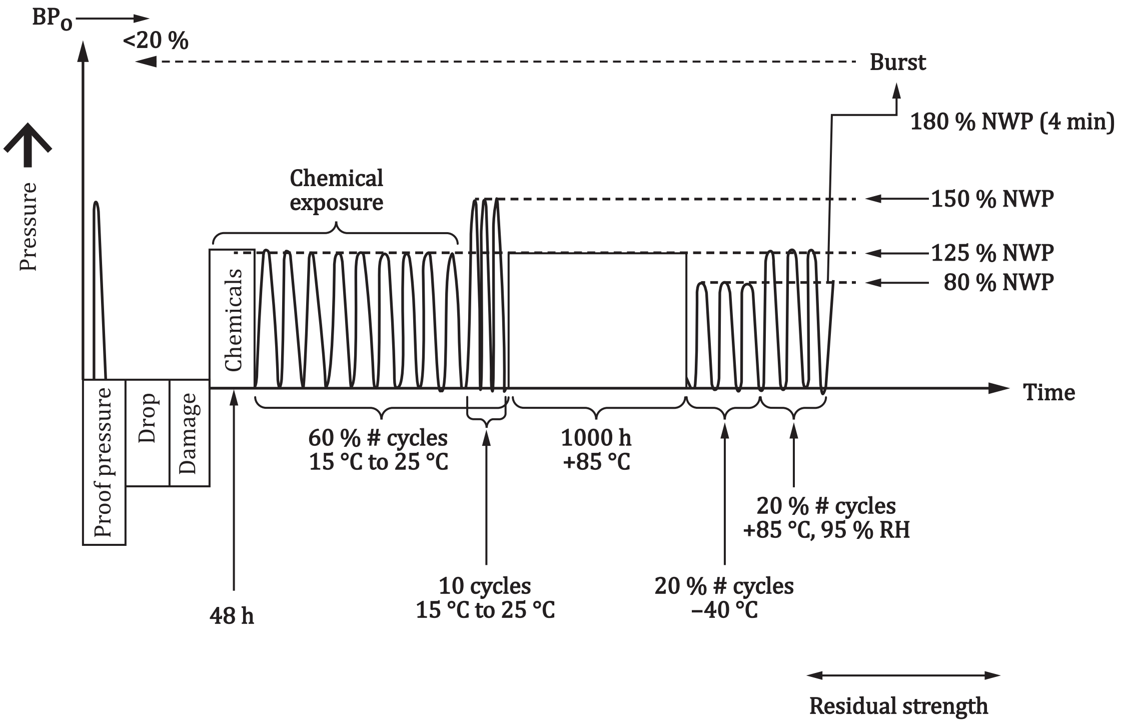
All containers tested shall have a burst pressure within ±10 % of the midpoint and greater than 225 % of the nominal working pressure and in no case less than the value necessary to meet the burst/nominal working pressure ratio requirement of 7.1, for Type 1 containers, or the stress ratio requirement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

17.5.4 Container test for performance durability

17.5.4.1 Test requirements

If all three pressure cycle life measurements determined per 17.5.2 are greater than 11 000 cycles or if they are all within ±25 % of each other, only one container shall be subjected to the tests specified in 17.5.4. 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.



NOTE BP$_0$ is the midpoint burst pressure of new containers.

Figure 3 — Verification test for performance durability (See 17.5.4.1.)

17.5.4.2 Proof pressure test

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

17.5.4.3 Drop test

Containers shall be subjected to the drop test conditioning specified in 17.3.7.2 a).

17.5.4.4 Surface damage test

Containers shall be subjected to the surface flaw conditioning specified in 17.3.6.2 a) or 17.3.6.2 c), except that 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 17.3.3.2.1 and 17.3.3.2.2, except that the container shall be preconditioned at −40 °C for 12 h prior to the pendulum impacts.

17.5.4.5 Chemical exposure and ambient pressure cycling

Containers shall be subjected to the chemical conditioning specified in 17.3.3.2.3, except that the container shall be held at the ambient temperature and 125 % of the nominal working pressure (±1 MPa) for 48 h before the container is subjected to further testing.

Containers shall be subjected to the pressure cycling test specified in 17.3.2 to 60 % 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 % of the nominal working pressure (±1 MPa).

17.5.4.6 High temperature static pressure test

Containers shall be pressurized to 125 % of the nominal working pressure (±1 MPa) while at a temperature of 85 °C. The container shall be held at this pressure and temperature for 1 000 h.

17.5.4.7 Extreme temperature pressure cycling test

Containers shall be pressure cycled at −40 °C or lower to 80 % of the nominal working pressure (±1 MPa) in accordance with the test procedure specified in 17.3.4.2 c), d) and e), except that the container shall be cycled to 20 % of 5 500, 7 500 or 11 000 cycles, as appropriate.

Containers shall be pressure cycled at 85 °C or higher to 125 % of the nominal working pressure (±1 MPa) in accordance with the test procedure specified in 17.3.4.2 a) and b), except that the container shall be cycled at 95 % relative humidity and to 20 % of 5 500, 7 500 or 11 000 cycles, as appropriate.

17.5.4.8 Hydraulic residual pressure test

Containers shall be pressurized to 180 % of the nominal working pressure and held for 4 min. The container shall not rupture.

17.5.4.9 Residual burst test

Containers shall be subjected to the burst test specified in 17.3.5. The container shall burst at a pressure that is at least 80 % of the burst pressure determined in 17.3.5.

17.5.5 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 No. 13, SAE J2579 or equivalent hydrogen and fuel cell vehicle standards.

17.6 Category C: design qualification conditions and limitations

17.6.1 Marking information

15.1.2 a) 8) does not apply.

17.6.2 Material tests for steel containers and liners

If the container or liner is made of steel, appropriate material tests in accordance with ISO 9809-1:2010, 10.2 to 10.4, or ISO 9809-2:2010, 10.2 to 10.4, shall be carried out on one liner. The tensile strength shall meet the container manufacturer's design specifications. For Type 1 and Type 2 containers the steel elongation shall be at least 14 %. For Type 3 containers the tensile strength and elongation shall meet the container manufacturer's design specifications.

17.6.3 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 7866:2012 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 container manufacturer's design specifications. The elongation shall be at least 12 %. For Type 3 liners using aluminum alloy, materials tests as required in ISO 7866:2012 10.2 and Annex B shall be carried out on one liner. The materials properties, including elongation, shall meet the container manufacturer's design specifications.

A suitable aluminium alloy for hydrogen service is AA6061 in the T6, T62, T651 or T6511 heat treats.

17.7 Qualification test results

A record of all tests for each design describing test setup, procedure and result shall be kept on file by the container manufacturer. These records shall include the complete Inspector's Record and the information contained in Table 7 and Table 8 for each container design tested.

Table 7 — Container design information (See 17.7)

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

Manufacturer ____ Part No. ____________

Service pressure _____________________ MPa

Hydrostatic test pressure _____________________ MPa

Autofrettage pressure _____________________ MPa

Minimum prescribed burst pressure ____________________MPa

Volume (water) _____________________ l

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

Table 8 — Container stress distribution information (See 17.7)

	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 ________________

Annex A
(informative)

Visual inspection

NOTE This informative Annex has been written in mandatory language to facilitate the 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 container manufacturer's recommendations and the inspection procedures provided in ISO 19078 or 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 container manufacturer and serial number, a replacement label supplied by the container 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 ISO 19078:2013, 7.4.1 or the Compressed Gas Association (CGA) C-6.4] that may cause damage shall be subjected to inspection procedures provided in ISO 19078:2013 or CGA C-6.4. Containers that have not experienced any rejectable damage may be returned to service; otherwise, the container shall be destroyed per ISO 19078:2013 or CGA C-6.4 or returned to the container manufacturer for evaluation.

Annex B
(informative)

Non-destructive examination

NOTE This informative Annex has been written in mandatory language to facilitate the 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 10.1 shall be determined using a method as described under 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 modelled 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 % of the nominal working pressure and the 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 BS 7910, section 8.4, by integrating the relationship between the rate of fatigue crack propagation, as established in B.2 e), and the range of crack driving force corresponding to the applied pressure cycle.

g) The incremental crack dimension or stress intensity factor calculated in B.2 f) should be compared with the limiting value, as per BS 7910, section 8.2.4.

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 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 10.1 shall be pressure cycled to failure in accordance with the test method in 17.3.2. 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

C.1 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.” (Not required for Category 3 containers)

“Container Service Life Ends After Use in a Single Vehicle — Container Transfer Between Vehicles is Prohibited.”

“Mounting Shall Be In Accordance With The Container Manufacturer’s Instructions.”

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 _________

C.2 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 __________________

C.3 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	Tensile strength MPa	Elongation %

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 ________________

Annex D
(informative)

Design qualification test rationale

D.1 Category A, B 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 the 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 % of the nominal working pressure). Note that a faster test time (lower number of pressure cycles until leakage occurs) can be achieved by cycling to higher pressures but that can elicit failure modes that could not occur in real world service.

See also the rationale in D.3, D.4 and D.5 for the 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 can 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 the 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 at 100 km/h.

D.1.4 Environmental fluids for exposure

D.1.4.1 General

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.

a) 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 fueling stations (methanol and gasoline).

b) 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.

c) 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.

d) 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.1.4.2 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.1.4.3 Acceptable results

Fueling station over-pressurization is constrained by fueling station requirements to less than or equal to 150 % of the nominal working pressure.

Laboratory data on static stress rupture used to define equivalent probability of stress rupture of composite strands after 4 min at 180 % of the nominal working pressure with after 10 h at 150 % of the nominal working pressure as the worst case[15]. Fueling stations are expected to provide over-pressure protection up to 150 % of the nominal working pressure.

Testing at the "end-of-life" provides assurance to survive fueling station failure throughout the 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 do not experience only a combination of extreme cold and extreme hot cycles during their lifetime. The 180 % of the nominal working pressure residual burst pressure at the end of cycle testing recognizes that a container at the end of life must survive possible fueling station overpressure exceeding 150 % of the nominal working pressure. Note that the temperature of the fluid in the container shall be monitored, as the 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 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 that 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 UN GTR No. 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[14] 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 industry standards.

The fire test conditions were based on vehicle-level tests by the Japanese Automobile Research Institute (JARI) and US vehicle manufacturers. A summary of data is found in Reference [14]. Key findings are as follows:

a) About 40 % 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 min to 60 min, the period of localized fire degradation on the storage containers lasted less than 10 min;

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 signalled 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 at 25 mm ± 10 mm 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 the reproducibility of results), the use of Liquefied Petroleum Gas (LPG) and wind guards are specified. Experience indicates that the controllability of the LPG fire is 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 the 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) one 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 should 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 can be customized to align with the actual fire exposure area and can 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 fire is reduced from the generic size to create a more challenging (and realistic) test.

D.1.9 Accelerated stress rupture test

The 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 h 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. The use of laboratory data to establish the equivalence of testing for stress rupture at 100 % of the nominal working pressure for 25 years and testing at 125 % of the nominal working pressure for 1 000 h (equal probability of failure from stress rupture) is described in Reference [15]. 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 Reference [16].

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 joule. 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

The 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[17]. 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 per hour;

— maximum permitted hydrogen concentration is 1 % by volume, i.e. 25 % LFL;

— maximum long term material temperature is 55 °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 °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 °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/h/l water capacity at a 15 °C testing temperature.

D.1.12 Boss torque test

A safety margin of 2 is applied to the container 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, and

— 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 shall demonstrate that it will leak and not "break" when a fatigue crack grows through the metal wall. Pressure cycle testing is conducted at 150 % 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 can only result in a leak condition. This test does not apply to Type 4 designs because a failure of the plastic liner, which is non-loadsharing, will not result in rupture of the container, and because the fatigue life of the reinforcing fibers is significantly greater than the required life of the container.

D.2 Category B design qualification tests

The rationale for Category B container tests are detailed in the ECE/TRANS/180/Add.13, UN GTR No. 13, 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 No. 13 for hydrogen and 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 × 750 cycles = 18 750 cycles total. The robustness of this specification is assured by the recognition that 18 750 cycles × 320 km (200 miles) per fueling cycle exceeds 6 million km (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 No. 13 for hydrogen and 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 miles). Based on these figures and 320 km to 480 km (200 miles to 300 miles) driven per full fueling, the maximum number of lifetime empty-to-full fuelings can be estimated as 1 200 to 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 km to 1 000 000 km (500 000 miles to 600 000 miles) 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 km to 480 km (200 miles to 300 miles) driven per full fueling, the maximum number of empty-to-full fuelings can be estimated as 1 650 to 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 miles) 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 to 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 to 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 h per day, 7 days per week with daily driving distances of 540 km to 720 km (335 miles to 450 miles). 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 km to 1 900 000 km (870 000 miles to 1 200 000 miles) is projected. Based on 320 km to 480 km (200 miles to 300 miles) driven per full fueling, the projected full-usage 15-year number of full fuelings could be 2 900 to 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 million km to 5,3 million km (2,2 million miles to 3,3 million miles).

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 the consideration of two scenarios of risk:

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

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

   ii) Expected vehicle lifetime range is taken to be 250 000 km.

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

   iv) 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).

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

2) Extended durability: extreme usage — where the vehicle sustains an extreme number of fuelings.

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

   ii) 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).

   iii) 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 km to 160 km traveled.

   iv) 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).

   v) 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.

   vi) Therefore, the extreme number of fuelings is taken as 5 500 = 3 × 590 000/322.

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

3) 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.

4) 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 ×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.

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2) Under preparation.

ICS 43.060.40; 71.100.20
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