TECHNICAL SPECIFICATION

ISO/TS 15869

First edition
2009-02-01

Gaseous hydrogen and hydrogen blends — Land vehicle fuel tanks

Hydrogène gazeux et mélanges d'hydrogène gazeux — Réservoirs de carburant pour véhicules terrestres

Reference number
ISO/TS 15869:2009(E)

PDF disclaimer

This PDF file may contain embedded typefaces. In accordance with Adobe's licensing policy, this file may be printed or viewed but shall not be edited unless the typefaces which are embedded are licensed to and installed on the computer performing the editing. In downloading this file, parties accept therein the responsibility of not infringing Adobe's licensing policy. The ISO Central Secretariat accepts no liability in this area.

Adobe is a trademark of Adobe Systems Incorporated.

Details of the software products used to create this PDF file can be found in the General Info relative to the file; the PDF-creation parameters were optimized for printing. Every care has been taken to ensure that the file is suitable for use by ISO member bodies. In the unlikely event that a problem relating to it is found, please inform the Central Secretariat at the address given below.

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of document:

— an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;

— an ISO Technical Specification (ISO/TS) represents an agreement between the members of a technical committee and is accepted for publication if it is approved by 2/3 of the members of the committee casting a vote.

An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

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.

ISO/TS 15869 was prepared by Technical Committee ISO/TC 197, *Hydrogen technologies*, with collaboration from Technical Committee ISO/TC 22, *Road vehicles*, and Technical Committee ISO/TC 58, *Gas cylinders*, Subcommittee SC 3, *Cylinder design*.

Introduction

Fuel tanks for on-board storage of compressed gaseous hydrogen and hydrogen blends as fuels for land vehicle service are required to maintain or improve the level of safety currently existing for land vehicle applications. These requirements are achieved by:

a) specifying service conditions precisely and comprehensively as a firm basis for both fuel tank design and use;

b) using an appropriate method to assess cyclic pressure fatigue life and to establish allowable defect sizes in metal tanks or liners;

c) requiring design qualification tests;

d) requiring non-destructive testing and inspection of all production fuel tanks;

e) requiring destructive tests on fuel tanks and tank material taken from each batch of fuel tanks produced;

f) requiring manufacturers to specify the acceptable in-service damage levels for their design; and

g) requiring manufacturers to specify as part of their design, the safe service conditions for their fuel tanks.

Designs meeting the requirements of this International Standard:

a) will have a fatigue life that exceeds the expected service; and

b) will demonstrate appropriate strength and durability for expected service conditions.

Gaseous hydrogen and hydrogen blends — Land vehicle fuel tanks

1 Scope

This International Standard specifies the requirements for lightweight refillable fuel tanks intended for the on-board storage of high-pressure compressed gaseous hydrogen or hydrogen blends on land vehicles.

This International Standard is not intended as a specification for fuel tanks used for solid, liquid hydrogen or hybrid cryogenic high-pressure hydrogen storage applications.

This International Standard is applicable for fuel tanks of steel, stainless steel, aluminium or non-metallic construction material, using any design or method of manufacture suitable for its specified service conditions.

This International Standard applies to the following types of fuel tank designs:

— Type 1: metal fuel tanks;

— Type 2: hoop-wrapped composite fuel tanks with a metal liner;

— Type 3: fully wrapped composite fuel tanks with a metal liner;

— Type 4: fully wrapped composite fuel tanks with no metal liner.

2 Normative references

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

ISO 306, *Plastics — Thermoplastic materials — Determination of Vicat softening temperature (VST)*

ISO 527-2, *Plastics — Determination of tensile properties — Part 2: Test conditions for moulding and extrusion plastics*

ISO 2808, *Paints and varnishes — Determination of film thickness*

ISO 4624, *Paints and varnishes — Pull-off test for adhesion*

ISO 6506-1, *Metallic materials — Brinell hardness test — Part 1: Test method*

ISO 7225, *Gas cylinders — Precautionary labels*

ISO 7866:1999, *Gas cylinders — Refillable seamless aluminium alloy gas cylinders — Design, construction and testing*

ISO 9809-1:1999, *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 9809-2:2000, *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 11114-4, *Transportable gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 4: Test methods for selecting metallic materials resistant to hydrogen embrittlement*

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

ISO/TS 14687-2, *Hydrogen fuel — Product specification — Part 2: Proton exchange membrane (PEM) fuel cell applications for road vehicles*

EN 1964-3:2000, *Transportable gas cylinders — Specification for the design and construction of refillable transportable seamless steel gas cylinders of water capacities from 0,5 litre up to and including 150 litres — Part 3: Cylinders made of seamless stainless steel with an Rm value of less than 1 100 MPa*

EN 12862:2000, *Transportable gas cylinders — Specification for the design and construction of refillable transportable welded aluminium alloy gas cylinders*

EN 13322-2:2003/A1:2006, *Transportable gas cylinders — Refillable welded steel gas cylinders — Design and construction — Part 2: Stainless steel*

ASTM B 117, *Standard Practice for Operating Salt Spray (Fog) Apparatus*

ASTM D 522, *Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings*

ASTM D 1308, *Standard Test Method for Effect of Household Chemicals on Clear and Pigmented Organic Finishes*

ASTM D 2344, *Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates*

ASTM D 2794, *Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)*

ASTM D 3170, *Standard Test Method for Chipping Resistance of Coatings*

ASTM D 3418, *Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry*

ASTM G 154, *Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials*

3 Terms and definitions

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

3.1
auto-frettage
pressure application procedure used in manufacturing composite fuel tanks with metal liners, which strains the liner past its yield point

NOTE Auto-frettage results in the liner having compressive stresses and the fibres having tensile stresses at zero internal pressure.

3.2
auto-frettage pressure
pressure within the over-wrapped composite fuel tank at which the required distribution of stresses between the liner and the over-wrap is established

3.3
batch of composite fuel tanks
group of not more than 200 fuel tanks plus fuel tanks for destructive testing or, if greater, one shift of successive production of fuel tanks, successively produced from qualified liners having the same size, design, specified materials of construction and manufacturing process

3.4
batch of metal fuel tanks/liners
group of not more than 200 fuel tanks/liners plus fuel tanks/liners for destructive testing or, if greater, one shift of successive production of metal fuel tanks/liners, successively produced having the same nominal diameter, wall thickness, design, specified material of construction, manufacturing process, equipment for manufacturing and heat treatment, and conditions of time, temperature and atmosphere during heat treatment

3.5
batch of non-metallic liners
group of not more than 200 liners plus liners for destructive testing or, if greater, one shift of successive production of non-metallic liners, successively produced having the same nominal diameter, wall thickness, design, specified material of construction and manufacturing process

3.6
burst pressure
pressure that causes the bursting of a pressure vessel subjected to a constant increase of pressure during a destructive test

3.7
controlled tension winding
process used in manufacturing hoop-wrapped composite fuel tanks with metal liners by which compressive stresses in the liner and tensile stresses in the over-wrap at zero internal pressure are obtained by winding the reinforcing filaments under high tension

3.8
design change
change in the selection of structural materials or dimensional changes exceeding the tolerances as on the design drawings

3.9
finished fuel tanks
fuel tanks that are ready for use, typical of normal production, complete with identification marks and external coating including integral insulation specified by the manufacturer, but free from non-integral insulation or protection

3.10
fully wrapped composite fuel tank
fuel tank with an over-wrap having a filament wound reinforcement both in the circumferential and axial direction of the fuel tank

3.11
hoop-wrapped composite fuel tank
fuel tank with an over-wrap having a filament wound reinforcement in a substantially circumferential pattern over the cylindrical portion of the liner such that the filament does not carry any significant load in a direction parallel to the longitudinal axis of the fuel tank

3.12
hydrogen blend
mixture of natural gas and hydrogen

3.13
hydrogen storage system
system on a land vehicle comprised of the fuel tank and all closure devices (e.g. shut-off valves, check valves and thermally activated pressure relief devices), as well as piping that contains hydrogen at the working pressure

3.14
leakage
release of gas through a crack, pore, unbonded or similar defect

NOTE Permeation through the wall of a Type 4 fuel tank that is less than the rates described in B.16 is not considered leakage.

3.15
liner
container that is used as an inner shell, on which reinforcing fibres are filament wound to achieve the necessary strength

3.16
manufacturer
organization responsible for the design, manufacturing and testing of fuel tanks

3.17
over-wrap
reinforcement system of filament and resin applied over the liner

3.18
thermally activated pressure relief device
device that activates by temperature to release pressure and prevent a fuel tank from bursting due to fire effects and that will activate regardless of fuel tank pressure

3.19
passenger vehicles
vehicles designed and constructed primarily for the carriage of persons (e.g. cars and buses)

3.20
pre-stress
process of applying auto-frettage or controlled tension winding

3.21
service conditions
conditions that the fuel tank will experience in service and that include on-road exposure to environmental factors (road salt, acids, bases, temperature extremes) and expected usage (pressure cycles associated with filling and discharge during service and driving, static pressure associated with vehicle parking, etc.)

3.22
settled pressure
gas pressure when a given settled temperature is reached

3.23
settled temperature
uniform gas temperature after any change in temperature caused by filling has dissipated

3.24
stress ratio
stress in fibre at specified minimum burst pressure divided by stress in fibre at working pressure

3.25
test pressure
required pressure applied during a pressure test

3.26
working pressure
nominal working pressure
settled pressure of compressed gas at a uniform temperature of 15 °C in a full fuel tank

4 Service conditions

4.1 General

The specified service conditions provide the basis for the design, manufacturing, inspection, and testing of fuel tanks that are to be mounted on land vehicles and used to store compressed gaseous hydrogen or hydrogen blends at ambient temperatures for use as a fuel on these vehicles.

The specified service conditions are also intended to provide information on how fuel tanks made in accordance with this International Standard may safely be used, for

a) manufacturers of fuel tanks,

b) owners of fuel tanks,

c) designers or contractors responsible for the installation of fuel tanks,

d) designers or owners of equipment used to refuel land vehicle fuel tanks,

e) suppliers of gaseous hydrogen and hydrogen blends, and

f) regulatory authorities that have jurisdiction over fuel tank use.

The service conditions do not cover external loading that may arise from vehicle collisions, etc.

4.2 Expected service

The expected service for which fuel tanks are safe shall be specified by the fuel tank manufacturer.

4.3 Working pressure

The working pressure shall be specified by the fuel tank manufacturer for gaseous hydrogen and hydrogen blends settled at a temperature of 15 °C.

4.4 Maximum filling pressure

Fuel tanks shall be designed to be filled up to a maximum pressure not exceeding 1,25 times the working pressure, regardless of filling conditions or temperature, and which settles to a pressure of not greater than the working pressure at the settled temperature of 15 °C.

4.5 Filling cycles

4.5.1 General

Except as permitted in 4.5.2, fuel tanks shall be designed for 11 250 fill cycles, representing a 15-year life of use in commercial heavy-duty vehicles (see Annex A).

4.5.2 Reduced number of filling cycles

A reduced number of 5 500 filling cycles may be specified for the lifetime of the vehicle. Fuel tanks with the reduced number of filling cycles may be qualified according to 9.2 or 9.5. In the case of fuel tanks with a reduced number of filling cycles and qualified according to 9.2, these shall only be used in conjunction with a tamper-proof counter system that records the number of fill cycles and terminates usage of the fuel tank before the reduced number of fill cycles is exceeded.

4.6 Design temperature

Fuel tanks shall be designed to be suitable for use in the following material temperature range: –40 °C to 85 °C. Transient gas temperatures during filling and discharge may vary locally beyond these limits.

4.7 Gas composition

Fuel tanks shall be designed to be filled with compressed gaseous hydrogen and/or hydrogen blends containing more than 2 % hydrogen by volume, combined with dry natural gas. The gas composition shall comply with the following:

a) compressed hydrogen gas shall comply with the composition specified in ISO/TS 14687-2;

b) compressed natural gas (CNG) used in hydrogen blends may vary as stated in the dry gas composition limits specified in ISO 11439.

4.8 External surfaces

Fuel tank external surfaces shall be designed to withstand mechanical and chemical exposure conditions as reflected in the type tests specified in Clause 9.

4.9 Fire effects

Fuel tanks shall be protected from fire effects using non-reclosing thermally activated pressure relief devices. Non-reclosing pressure-activated pressure relief devices can only be used in parallel with thermally activated pressure relief devices. A thermally activated pressure relief device shall not under any circumstances require the operation of the pressure-activated pressure relief device in order to function.

NOTE In the selection of thermally activated pressure relief devices, the requirements of the ANSI/IAS PRD 1-1998/ Addenda PRD 1a-1999 can be used as guidance until a standard on pressure relief devices for hydrogen service is available.

The fire protection of fuel tanks may also be supplemented by the use of thermal insulation.

5 Information to be recorded

5.1 General

The fuel tank manufacturer shall keep on file the information specified herein. This information shall be retained for the intended life of the fuel tank.

5.2 Statement of service

A statement of service shall be provided to the user. This statement of service shall include the following:

a) the name and address of the fuel tank manufacturer;

b) a description of the fuel tank design, including fuel tank identification, working pressure (MPa), fuel tank type, diameter (mm), length (mm), internal volume (l), empty weight (kg) and valve thread type;

c) a statement that the fuel tank design is suitable for use in the service conditions provided in Clause 4;

d) a statement of the maximum service conditions for which the fuel tank was designed;

e) a statement of the maximum number of filling cycles for which the fuel tank was designed;

f) a statement of the working pressure for which the fuel tank was designed;

g) a specification for the fire protection system approved by the fuel tank manufacturer using non-reclosing thermally activated pressure relief devices and, if used, thermal insulation;

h) a specification for the support methods, protective coatings and any other items required, but not provided with the fuel tank;

i) any other information and instructions necessary to ensure the safe use and inspection of the fuel tank.

5.3 Design drawings and information

All fuel tank drawings and related technical data shall be kept on file by the fuel tank manufacturer and shall show the following information:

a) title, reference number, date of issue and revision numbers with dates of issue, if applicable;

b) reference to a Type 1, Type 2, Type 3 or Type 4 design;

c) dimensions complete with tolerances, including details of end closure shapes with minimum thickness and openings;

d) mass, complete with tolerance;

e) material specifications, complete with minimum mechanical and chemical properties and tolerance ranges and, for metal fuel tanks or metal liners, the specified hardness range;

f) other data such as auto-frettage pressure range, minimum test pressure, details of the fire protection system and of any exterior protective coating;

g) the gas that the fuel tank is designed to carry;

h) the working pressure of the design.

5.4 Stress analysis report

When a stress analysis is required to be carried out, the stress analysis report shall be kept on file and shall include a table summarizing the calculated stresses.

NOTE Verification of the stress ratios may be performed using strain gauges or an equivalent method. An example of an acceptable method is provided in Annex C.

5.5 Material property data

A detailed description of the materials and tolerances of the material properties used in the design shall be kept on file. Test data shall also be presented characterizing the mechanical properties and the suitability of the materials for service under the conditions specified in Clause 4.

5.6 Fire protection

The arrangement of the non-reclosing thermally activated pressure relief devices, and insulation if provided, that will protect the fuel tank from sudden rupture when exposed to the fire conditions in B.9 shall be specified by the fuel tank manufacturer.

5.7 Manufacturing data

Details of all fabrication processes, tolerances, non-destructive examinations, type tests, batch tests and production tests shall be specified and kept on file by the fuel tank manufacturer. The manufacturer shall specify the burst pressure range for the design. In no case shall the minimum specified burst pressure be less than the minimum burst pressure specified in this International Standard.

Surface finish, thread details, acceptance criteria for ultrasonic scanning (or equivalent) and maximum lot sizes for batch tests shall also be specified by the fuel tank manufacturer and kept on file.

6 Materials

6.1 Compatibility

Materials used shall be suitable for the service conditions specified in Clause 4. The design shall not have incompatible materials in contact with each other. All metallic materials in contact with hydrogen and hydrogen blends shall be compatible with hydrogen according to B.2.

NOTE Guidance on hydrogen compatibility can be found in the documents listed in the Bibliography.

6.2 Steel

Steels for fuel tanks and liners shall conform to the materials requirements of 6.1 to 6.4 of ISO 9809-1:1999, or 6.1 to 6.3 of ISO 9809-2:2000, as appropriate.

6.3 Stainless steels

Stainless steels shall conform to the materials requirements of 4.1 to 4.4 of EN 1964-3:2000. Welded stainless steels shall conform to the materials requirements of 4.1 to 4.3 of EN 13322-2:2003/A1:2006, as appropriate.

6.4 Aluminium alloys

Aluminium alloys shall conform to the materials requirements of 6.1 and 6.2 of ISO 7866:1999. Welded aluminium alloys shall conform to the materials requirements of 4.2 and 4.3 of EN 12862:2000.

Aluminium alloys not covered by the materials requirements of ISO 7866:1999 may be used, provided that hydrogen compatibility is demonstrated according to the method specified in B.2.

6.5 Resins

The material for impregnation may be thermosetting or thermoplastic resins. Examples of suitable matrix materials are epoxy, modified epoxy, polyester and vinylester thermosetting plastics, as well as polyethylene and polyamide thermoplastic.

6.6 Fibres

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

The fuel tank manufacturer shall keep on file for the intended life of the fuel tank design the published specifications for composite materials and the material manufacturer's recommendations for storage conditions and shelf life. The fuel tank manufacturer shall keep on file, for the intended life of each batch of fuel tanks, the fibre manufacturer's certification that each shipment conforms to the manufacturer's specifications for the product.

6.7 Plastic liners

The polymeric material used for plastic liners shall be compatible with the service conditions specified in Clause 4.

6.8 Metal end bosses

The metal end bosses connected to a non-metallic liner shall be made of material compatible with the service conditions specified in Clause 4.

7 Design requirements

7.1 General

This International Standard neither provides design formulae nor lists permissible stresses or strains, but requires adequacy of design to be demonstrated by testing to show that the fuel tanks are capable of consistently passing the material, type, production and batch tests that it specifies.

7.2 Test pressure

The minimum test pressure used during manufacturing shall be 1,5 times the working pressure.

7.3 Burst pressure and fibre stress ratio

7.3.1 Fuel tank

The minimum actual burst pressure of the fuel tank shall not be less than the values given in Table 1. Composite reinforcement used on fuel tanks shall also meet the minimum stress ratio requirements of Table 1.

Verification of the stress ratios may be done by calculation. When the calculation method is used, the stress ratio calculations shall include:

a) an analysis method with capability for non-linear materials, such as a special purpose computer program or a finite element analysis program;

b) correct modelling of the elastic-plastic stress-strain curve for the liner material;

c) correct modelling of the mechanical properties of the composite materials;

d) calculations at auto-frettage pressure, zero pressure after auto-frettage, working pressure and minimum burst pressure;

e) account for the pre-stresses from the winding tension;

f) minimum burst pressure, chosen such that the calculated stress at minimum burst pressure divided by the calculated stress at the working pressure meets the stress ratio requirements for the fibre used;

g) when analyzing fuel tanks with hybrid reinforcement (two or more different fibres), consideration of the load share between the different fibres based on the different elastic moduli of the fibres. The stress ratio requirements for each individual fibre type shall be in accordance with the values given in Table 1.

Verification of the stress ratios may also be performed using strain gauges. An acceptable method is provided in Annex C.

Table 1 — Minimum stress ratios and burst pressures

Construction	Minimum stress ratio			Minimum actual burst pressure [a]			
	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4
All-metal				2,25			
Glass	2,65	3,5	3,5		2,4	3,4	3,5
Aramid	2,25	3,0	3,0		2,25	2,9	3,0
Carbon (working pressures less than 35 MPa)	2,25	2,25	2,25		2,25	2,25	2,25
Carbon (working pressures greater than or equal to 35 MPa)	2,0	2,0	2,0		2,0	2,0	2,0
Hybrid	b						

[a] Burst pressures are expressed as a factor of the working pressure.

[b] Stress ratios and burst pressures shall be calculated in accordance with 7.3.1 g). The stress ratio requirements for each individual fibre type shall be in accordance with the values given above.

7.3.2 Liner

For Type 2 designs, the un-reinforced metal liner shall have a minimum burst pressure of 1,25 times the working pressure.

7.4 Stress analysis

A stress analysis shall be performed to justify the minimum design wall thickness. It shall include the determination of the stresses in the liners and fibres of composite designs.

For Type 2 and Type 3 designs, the stresses in the composite and in the liner after pre-stress shall be calculated at zero pressure, working pressure, test pressure and design burst pressure. The calculations shall use suitable analysis techniques taking account of non-linear material behaviour of the liner to establish the stress distributions.

For Type 2 and Type 3 designs using auto-frettage to provide pre-stress, the limits within which the auto-frettage pressure shall fall shall be calculated and specified. For Type 2 and Type 3 designs using controlled tension winding to provide pre-stress, the temperature at which it shall be performed, the tension required in each layer of the composite and the consequent pre-stress in the liner shall be calculated.

For Type 4 designs, the stresses in the composite shall be calculated in the tangential and longitudinal direction of the fuel tank. The pressures used for these calculations shall be zero pressure, working pressure, test pressure and design burst pressure. The calculations shall use suitable analysis techniques to establish the stress distribution throughout the fuel tank.

7.5 Maximum defect size

For Type 1, Type 2 and Type 3 designs, the maximum defect size for non-destructive examinations (NDE) shall be established by a method suitable for the design. This method shall demonstrate that a fuel tank with defects of the specified defect size will meet the ambient temperature pressure cycling requirements of B.7. The NDE method shall be capable of detecting the maximum defect size allowed.

NOTE An example of a suitable method for establishing the maximum defect size is given in Annex D.

7.6 Fire protection

The fuel tank, its materials, non-reclosing thermally activated pressure relief devices and any added insulation or protective material or non-reclosing pressure-activated pressure relief devices, shall be designed collectively to ensure adequate safety during fire conditions of the test specified in B.9. In no case shall a pressure relief device be composed of thermally activating and pressure-activating functions acting in series such that both functions are required to activate to prevent a fuel tank from bursting due to fire effects.

Provided that the finished fuel tank with its fire protection system has passed the requirements of the bonfire test in B.9, alternative installation configurations for the fire protection system can be used if it can be demonstrated to provide the same or an improved level of safety. The final fire protection system used for vehicle installations involving multiple fuel tanks may require a different arrangement or number of non-reclosing thermally activated pressure relief devices.

If the configuration of fuel tanks results in the possibility of multiple fuel tanks having to vent through one single pressure relief device (PRD), then the bonfire test shall flow that full amount of hydrogen through the PRD associated with the fuel tank that is venting. It is not necessary to subject the extra fuel tank(s) that contain this additional hydrogen to the bonfire, provided that a single fuel tank has already passed the bonfire test with its own PRD.

NOTE 1 The non-reclosing thermally activated pressure relief device that is part of the fuel tank manufacturer specified fire protection system is not necessarily provided with the fuel tank. It is, however, required that the effectiveness of this fire protection system be demonstrated.

NOTE 2 It should not be possible to isolate the non-reclosing thermally activated pressure relief device from the fuel tank by the normal operation or failure of another component.

8 Construction and workmanship

8.1 Materials

Type 1 designs and Type 2 liners shall be of seamless construction using steel or aluminium alloys that comply with the materials requirements in 6.2 or 6.4, as appropriate. Type 3 liners shall be constructed from steel, aluminium alloys, stainless steels, welded stainless steels or welded aluminium alloys that comply with the materials requirements in 6.2, 6.3 or 6.4, as appropriate.

8.2 Type 3 metal liner

For Type 3 designs, the compressive stress in the liner at zero pressure and the design temperature range shall not cause the liner to buckle or crease.

NOTE During pressurization, a Type 3 design has a behaviour in which the displacements of the composite overwrap and the metal liner are linearly superimposed. Due to different manufacturing techniques, this International Standard does not give a definite method for design.

The welding of stainless steel liners shall conform to 6.1, 6.2 and 6.4 of EN 13322-2:2003/A1:2006, and the welding of aluminium alloy liners shall conform to 4.1.2 and 6.1 of EN 12862:2000.

For Type 3 liners subjected to cold-forming or cryo-forming processes, heat treatment of the pre-form component is not required. Liners that have been cold-formed or cryo-formed shall not be subjected to any subsequent heat treatment or to additional heat application, such as welding.

8.3 Neck threads, neck ring, foot ring, attachment for support

Openings with tapered or parallel threads may be used. Threads shall be clean cut, even and without surface discontinuities to gauge and shall conform to International Standards.

When a neck ring, foot ring or attachment for support is provided, it shall be of a material compatible with that of the fuel tank and shall be securely attached by a method other than welding, brazing or soldering.

8.4 Forming

For Type 1 or Type 2 aluminium fuel tanks and liners, a forming process such as fusion welding shall not be used to fully close and seal the ends. The base ends of Type 1 steel fuel tanks that have been closed by forming shall be inspected using NDE, methods in 8.2.4 of ISO 9809-1:1999 or other equivalent techniques. Metal shall not be added in the process of closure at the end. Each fuel tank shall be examined before end forming operations for thickness and surface finish.

After end forming, the fuel tanks shall be heat treated to the hardness range specified for the design. Localized heat treatment shall not be used.

8.5 Fibre winding

Type 2, Type 3 and Type 4 fuel tanks shall be fabricated from a liner over-wrapped with continuous filament windings. Fibre winding operations shall be computer or mechanically controlled. The fibres shall be applied under controlled tension during winding.

During winding, the significant variables shall be monitored to demonstrate that they remain within specified tolerances. The results shall be documented in a winding record that shall be retained by the fuel tank manufacturer for the intended life of each batch of fuel tanks. These variables can include but are not limited to:

a) fibre type, including sizing;

b) manner of impregnation;

c) winding tension;

d) winding speed;

e) number of rovings;

f) band width;

g) type of resin and composition;

h) temperature of the resin;

i) temperature of the liner; and

j) winding angle.

8.6 Curing of thermosetting resins

If a thermosetting resin is used, the resin shall be cured after the fibre winding is complete. Thermosetting resins shall be cured by heating, using a predetermined and controlled time-temperature profile. During the curing, the curing cycle (i.e. the time-temperature history) shall be documented and retained by the fuel tank manufacturer for the intended life of each batch of fuel tanks.

The maximum curing time and temperature for fuel tanks with aluminium alloy liners shall not adversely affect metal, resin and fibre properties.

8.7 Auto-frettage

Auto-frettage, if used, shall be carried out before the hydraulic test specified in 10.1 h). The auto-frettage pressure shall be within the limits established in 7.4. The fuel tank manufacturer shall establish the method to verify that the appropriate pressure is applied. Records of auto-frettage pressure shall be retained by the fuel tank manufacturer for the intended life of each batch of fuel tanks.

8.8 Exterior environmental protection

Exterior protection may be provided by using any one of the following:

a) a surface finish giving adequate protection (e.g. metal sprayed on aluminium, anodizing);

b) a suitable fibre and matrix material (e.g. carbon fibre in resin);

c) a protective coating (e.g. organic coating, paint).

If a protective coating is part of the design, the coatings shall be evaluated using the test methods in B.1.

Any coatings applied to fuel tanks shall be such that neither the coating nor the application process adversely affects the mechanical properties of the fuel tank. The coating shall be designed to facilitate subsequent in-service inspection, and the manufacturer shall provide guidance on coating treatment during such inspection to ensure the continued integrity of the fuel tank.

9 Type (qualification) tests

9.1 Qualification of new designs

The fuel tank material, design, manufacturing process and examination shall be proved to be adequate for their intended service by meeting the requirements of the type tests specified in 9.2 for generic land vehicle use. Alternatively, at the manufacturer's option, fuel tanks that are to be permanently mounted onboard on-road four-wheel passenger vehicles may have their material, design, manufacturing process and examination proved to be adequate for their intended service by meeting the requirements of the type tests specified in 9.5.

Type tests shall be conducted on each new design using finished fuel tanks that are representative of normal production, complete with identification marks. If more fuel tanks or liners are subjected to the tests than are required, all results shall be documented. All fuel tanks subjected to type tests shall be made unserviceable after the tests.

The fuel tank manufacturer shall retain the type test results for the intended service life of the fuel tank design. The test data shall also document the dimensions, wall thickness and weights of each of the tested fuel tank.

9.2 Generic type tests

9.2.1 General

Unless otherwise permitted by 9.3, Type 1, 2, 3 and 4 designs shall be subjected to the applicable type tests listed in Table 2.

Table 2 — Summary of generic type tests

Test		Number of fuel tanks required for testing	Applicable to type			
			1	2	3	4
9.2.2 to 9.2.4	Material tests for metal fuel tanks and liners	1 fuel tank or liner	✓	✓	✓	
9.2.5	Material tests for plastic liners	1 liner				✓
9.2.6	Resin properties	composite samples		✓	✓	✓
9.2.7	Hydrostatic burst pressure	3 plus 1 liner	✓	✓ ✓	✓	✓
9.2.8	Ambient temperature pressure cycling	2	✓	✓	✓	✓
9.2.9	Leak-before-break (LBB)	3	✓	✓	✓	✓
9.2.10	Bonfire	1	✓	✓	✓	✓
9.2.11	Penetration	1	✓	✓	✓	✓
9.2.12	Chemical exposure	1		✓	✓	✓
9.2.13	Composite flaw tolerance	1		✓	✓	✓
9.2.14	Accelerated stress rupture	1		✓	✓	✓
9.2.15	Extreme temperature pressure cycling	1		✓	✓	✓
9.2.16	Impact damage	1, 2 or 3			✓	✓
9.2.17	Permeation	1				✓
9.2.18	Boss torque	1				✓
9.2.19	Hydrogen gas cycling	1				✓

9.2.2 Material tests for steel fuel tanks and liners

If the fuel tank or liner is made of steel, appropriate material tests in accordance with 10.2 to 10.4 of ISO 9809-1:1999 or 10.2 to 10.4 of ISO 9809-2:2000 shall be carried out on one liner. The tensile strength shall meet the manufacturer's design specifications. For Type 1 and Type 2 designs, the steel elongation shall be at least 14 %. For Type 3 designs, the tensile strength and elongation shall meet the manufacturer's design specifications.

The hydrogen compatibility of steels in contact with hydrogen shall be demonstrated in accordance with B.2. Steels that conform to 6.3 and 7.2.2 of ISO 9809-1:1999 are exempted from this test.

9.2.3 Material tests for aluminium alloy fuel tanks and liners

For Type 1 fuel tanks and Type 2 liners using aluminium alloy, appropriate material tests as required in ISO 7866:1999, 10.2 and 10.3, as well as Annexes A and B shall be carried out on one fuel tank or liner. The materials properties shall meet the manufacturer's design specifications. The elongation shall be at least 12 %.

For Type 3 liners using aluminium alloy, materials tests as required in ISO 7866:1999, 10.2 and Annex B shall be carried out on one liner. The materials properties, including elongation, shall meet the manufacturer's design specifications.

For Type 3 liners using welded aluminium alloys, the requirements in 7.2.3 to 7.2.7 of EN 12862:2000 shall be followed, as well as Annexes A and B, excluding B2.2 thereof.

The hydrogen compatibility of aluminium alloys in contact with hydrogen shall be demonstrated in accordance with B.2. Aluminium alloys that conform to 6.1 and 6.2 of ISO 7866:1999 are exempted from this test.

9.2.4 Material tests for stainless steel liners

Materials used for stainless steel liners shall follow the requirements in 7.1.2.1 and 7.1.2.4 of EN 1964-3:2000.

Materials used for welded stainless steel liners shall follow the requirements in 8.4 to 8.7 of EN 13322-2:2003/A1:2006.

The hydrogen compatibility of stainless steels in contact with hydrogen shall be demonstrated in accordance with B.2.

9.2.5 Material tests for plastic liners

One liner shall be subjected to the following requirements:

a) The tensile yield strength and ultimate elongation shall be determined in accordance with B.3 and shall meet the requirements therein.

b) The softening temperature shall be determined in accordance with B.4 and shall meet the requirements therein.

9.2.6 Resin properties tests

For Type 2, Type 3 and Type 4 designs, samples representative of the composite over-wrap shall be tested in accordance with B.5. Resin materials shall meet the requirements therein.

9.2.7 Hydrostatic burst pressure test

For Type 2 designs, one liner shall be hydrostatically pressurized to failure in accordance with B.6. The burst pressure shall exceed 1,25 times the working pressure.

For all designs, three fuel tanks shall be hydrostatically pressurized to failure in accordance with B.6. For each fuel tank, the burst pressure shall exceed the specified minimum burst pressure given in Table 1. In no case shall the burst pressure be less than the value necessary to meet the stress ratio requirements in Table 1. The average of the burst pressure results of the three fuel tanks shall be recorded for future reference (see 10.2.2).

9.2.8 Ambient temperature pressure cycling test

For all designs, two fuel tanks shall be pressure cycled at ambient temperature in accordance with B.7 and meet the requirements therein.

9.2.9 Leak-before-break (LBB) test

For all designs, three fuel tanks shall be tested in accordance with B.8 and shall meet the requirements therein.

9.2.10 Bonfire test

For all designs, one or two fuel tanks as appropriate shall be tested in accordance with B.9 and meet the requirements therein.

9.2.11 Penetration test

For all designs, one fuel tank shall be tested in accordance with B.10 and meet the requirements therein.

9.2.12 Chemical exposure test

For Type 2, Type 3 and Type 4 designs, one fuel tank shall be tested in accordance with B.11 and meet the requirements therein.

9.2.13 Composite flaw tolerance test

For Type 2, Type 3 and Type 4 designs, one fuel tank shall be tested in accordance with B.12 and meet the requirements therein.

9.2.14 Accelerated stress rupture test

For Type 2, Type 3 and Type 4 designs, one fuel tank shall be tested in accordance with B.13 and meet the requirements therein.

9.2.15 Extreme temperature pressure cycling test

For Type 2, Type 3 and Type 4 designs, one fuel tank shall be tested in accordance with B.14 and meet the requirements therein.

9.2.16 Impact damage test

For Type 3 and Type 4 designs, one or more finished fuel tanks shall be tested in accordance with B.15 and meet the requirements therein.

9.2.17 Permeation test

For Type 4 designs, one fuel tank shall be tested for permeation in accordance with B.16 and meet the requirements therein.

9.2.18 Boss torque test

For Type 4 designs, one fuel tank shall be tested in accordance with B.17 and meet the requirements therein.

9.2.19 Hydrogen gas cycling test

For Type 4 designs, one fuel tank shall be tested in accordance with B.18 and meet the requirements therein.

Fuel tank designs that are not used in permanently mounted on-road passenger vehicles and that will only be used in a dedicated hydrogen slow fill (greater than 5 minutes) operation need not to perform this hydrogen cycle.

9.3 Exemptions to generic type tests

As an alternative to the requirements in 9.2, Type 1 steel design meeting the requirements of either ISO 9809-1:1999 or ISO 9809-2:2000 and the additional requirements specified in 7.6 and 8.8 of this International Standard may only be subjected to the bonfire test in 9.2.10 and the hydrogen compatibility tests in B.2.

As an alternative to the requirements in 9.2, Type 1 aluminium alloy design meeting the requirements of ISO 7866:1999 and the additional requirements specified in 7.6 and 8.8 of this International Standard may only be subjected to the bonfire test in 9.2.10 and the hydrogen compatibility tests in B.2.

9.4 Qualification of design changes

Design changes may be qualified through a reduced test program as given in Table 3. Design changes that exceed the changes defined in Table 3 shall be qualified by a complete test program.

A fibre shall be considered to be of a new fibre type when any of the following conditions apply:

a) the fibre is of a different classification, e.g. glass, aramid, carbon;

b) the fibre is produced from a different precursor (starting material), e.g. polyacrylonitrile (PAN), pitch for carbon;

c) the nominal fibre modulus specified by the fibre manufacturer differs by more than ± 5 % from that defined in the prototype-tested design;

d) the nominal fibre strength specified by the fibre manufacturer differs by more than ± 5 % from that defined in the prototype-tested design.

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

Table 3 — Qualification tests for design changes

Test No.	Test	Design change: Fibre manufacturer	Materials: Fibre	Materials: Resin	Materials: Metal fuel tank or liner	Materials: Plastic liner	Length: ⩽ 50 %	Length: > 50 %	Diameter [a]: ⩽ 20 %	Diameter [a]: > 20 %	Working pressure [a] ⩽ 20 %	Dome shape	Opening size	Coating	End boss design [b]	Fire protection system [c]	Manufacturer process [d]
9.2.7	Burst	X	X		X		X	X	X	X	X	X	X				X
9.2.8	Ambient cycle	X	X		X	X		X	X	X	X	X	X				X
9.2.9	LBB	X	X														
9.2.10	Bonfire		X		X			X		X						X	
9.2.11	Penetration		X	X	X				X [e]	X							
9.2.12	Chemical exposure		X	X	X	X								X			
9.2.13	Composite flaw		X	X	X					X							
9.2.14	Accelerated stress rupture	X	X	X	X												
9.2.16	Impact damage	X	X	X	X			X	X	X							
9.2.17	Permeation					X						X			X		
9.2.18	Boss torque					X						X			X		
9.2.19	Hydrogen gas					X						X			X		
B.2	Hydrogen compatibility				X												
6 9.2.2 9.2.3 9.2.4 9.2.5 9.2.6	Materials (as appropriate)	X	X	X	X	X	X	X	X	X	X	X	X		X		X

[a] Only when thickness changes proportional to diameter and/or pressure change; otherwise qualify as a new design.

[b] Test not required if the stresses in the neck are equal to the original or reduced by the design change (e.g. reducing the diameter of internal threads or changing the boss length), the liner to boss interface is not affected and the original materials are used for boss, liner and seals.

[c] Change in fire protection system, non-reclosing thermally activated pressure relief device or location of non-reclosing thermally activated pressure relief device.

[d] Any deviation from the manufacturing parameters specified in 5.7 is a change in the manufacturing process.

[e] Required if the diameter decreases.

9.5 Alternative type tests

At the manufacturer's option, fuel tanks that are to be permanently mounted onboard on-road four-wheel passenger vehicles may be qualified by performing the tests given in Table 4 and the tests specified in Annex E.

The fuel tanks subjected to the tests of Annex E may be integrated into a hydrogen storage system including all closure devices (such as shut-off valves, check valves, pressure relief devices, etc.) and piping that contain hydrogen at the working pressure.

Table 4 — Summary of alternative type tests

Test		Number of fuel tanks required for testing	Applicable to type			
			1	2	3	4
9.2.2 to 9.2.4	Material tests for metal fuel tanks and liners	1 fuel tank or liner	✓	✓	✓	
9.2.5	Material tests for plastic liners	1 liner				✓
9.2.6	Resin properties	Composite samples		✓	✓	✓
9.2.7	Hydrostatic burst pressure	3 plus 1 liner	✓	✓ ✓	✓	✓
9.2.8	Ambient temperature pressure cycling	2	✓	✓	✓	✓
9.2.9	Leak-before-break (LBB)	3	✓	✓	✓	✓
9.2.10	Bonfire [a]	1 or 2	✓	✓	✓	✓
9.2.11	Penetration	1	✓	✓	✓	✓
9.2.12	Chemical exposure [b]	1		✓	✓	✓
9.2.13	Composite flaw tolerance [b]	1		✓	✓	✓
9.2.16	Impact damage	1, 2 or 3			✓	✓
9.2.18	Boss torque	1				✓

[a] The bonfire test in 9.2.10 shall be conducted on either the individual fuel tanks or on the hydrogen storage system following integration of the fuel tanks into the system.

[b] The chemical exposure test and the composite flaw tolerance test shall be combined into one modified test on one fuel tank. This modified test shall involve introducing the flaw cuts from B.12 into the fuel tank being exposed to the chemicals according to B.11. The fuel tank shall then be filled with a non-corrosive fluid such as oil, inhibited water or glycol, and hydraulically pressure cycled from not more than 2 MPa to not less than 1,25 times the working pressure at a rate not to exceed 10 cycles per minute. The fuel tank shall be pressure cycled for the number of cycles specified in 4.5, without failure. The last 10 cycles shall be to 1,5 times working pressure to demonstrate capability to survive over-pressurization during refuelling station failure at end of service. The fuel tank shall then be burst-tested in accordance with B.6 and exceed a pressure of 1,8 times the working pressure.

10 Production and batch tests

10.1 Production tests

Production verifications and tests shall be carried out as follows on all fuel tanks produced in a batch.

Each fuel tank shall be subject to the following verifications during manufacturing or after completion:

a) NDE of metallic fuel tanks and liners in accordance with Annex B of ISO 9809-1:1999, Annex C of EN 1964-3:2000 or Annex B of EN 13322-2:2003/A1:2006 as appropriate, or a demonstrated equivalent method, to confirm that the maximum defect size does not exceed the size specified in the design as determined in accordance with 7.5. The NDE method shall be capable of detecting the maximum defect size allowed;

b) examination of welded stainless steel liners in accordance with 6.8.2 of EN 13322-2:2003/A1:2006, and welded aluminium alloy liners in accordance with 6.2.1 (second paragraph) and 6.2.3 of EN 12862:2000;

c) inspection of plastic liners to confirm that the maximum defect size present is less than the size specified in the design;

d) the verification of critical dimensions and mass of the finished fuel tanks, liners and over-wrapping are within design tolerances;

e) verification of conformance to the manufacturer's specified surface finish with special attention to deep drawn surfaces and folds or laps in the neck or shoulder of forged or spun end enclosures or openings;

f) verification of the markings;

g) hardness tests or equivalent tests of metallic fuel tanks and liners in accordance with B.19, carried out after the final heat treatment. The values thus determined shall be in the range specified for the design;

h) hydraulic test of finished fuel tanks in accordance with B.20. For Type 1, Type 2 and Type 3 designs, the permanent volumetric expansion shall not exceed the limit of permanent volumetric expansion specified by the fuel tank manufacturer for the test pressure used. In addition, in no case shall the permanent expansion exceed 5 % of the total volumetric expansion measured under the test pressure. For Type 4 designs, the manufacturer shall define the appropriate limit of elastic expansion for the test pressure used, but in no case shall the elastic expansion of any fuel tank exceed the average batch value by more than 10 %;

i) leak test on Type 4 fuel tanks or liners in accordance with B.21, except that the pressure used may be less than the working pressure.

10.2 Batch tests

10.2.1 General requirements

Batch tests shall be carried out on each batch of fuel tanks.

Batch tests shall be conducted on finished liners and fuel tanks that are representative of normal production, complete with identification marks. The fuel tanks and liners required for testing shall be randomly selected from each batch. If more fuel tanks are subjected to the tests than are required, all results shall be documented.

Batches of fuel tanks shall be proved to be adequate for their intended service by meeting the requirements of the batch tests specified in 10.2.2. The fuel tank manufacturer shall retain the batch test results and relevant data for each batch (e.g. cast number) for the intended life of the fuel tanks in the batch. All fuel tanks subjected to batch tests shall be made unserviceable after the tests.

10.2.2 Required tests

One fuel tank shall be subjected to the hydrostatic burst pressure test in accordance with B.6. The fuel tank burst pressure shall exceed the specified minimum burst pressure and stress ratio requirement given in Table 1. In addition, the burst pressure shall exceed 90 % of the average of the results obtained during the hydrostatic burst test of 9.2.7.

One fuel tank shall be subjected to pressure cycle testing in accordance with the requirements in 10.2.3. The fuel tank used for the pressure cycle test in 10.2.3 may also be used for the burst pressure test.

For Type 1, Type 2 and Type 3 designs, a further fuel tank, liner or sample representative of a finished fuel tank or liner shall be subjected to the following tests:

a) verification of the critical dimensions of the design;

b) tensile tests for steel fuel tanks or liners, in accordance with 10.2 of ISO 9809-1:1999 or 10.2 of ISO 9809-2:2000, as appropriate. Tensile tests for aluminium alloy fuel tanks or liners, in accordance with 10.2 of ISO 7866:1999. Tensile tests for stainless steel liners, in accordance with 7.1.2.1 of EN 1964-3:2000. Tensile tests for welded stainless steel liners, in accordance with 8.4 of EN 13322-2:2003/A1:2006. Tensile tests for welded aluminium liners, in accordance with 7.2.3 and 7.2.4 of EN 12862:2000. The test results shall satisfy the requirements of the design;

c) impact tests for steel fuel tanks or liners, in accordance with 10.4 of ISO 9809-1:1999 or 10.4 of ISO 9809-2:2000, as appropriate, and meet the requirements therein. Impact tests for stainless steel liners in accordance with 7.1.2.4 of EN 1964-3:2000, and meet the requirements therein. Impact tests for welded stainless steel liners in accordance with 8.6 of EN 13322-2:2003/A1:2006, and meet the requirements therein;

d) bend tests for welded stainless steel liners, in accordance with 8.5 of EN 13322-2:2003/A1:2006, and for welded aluminium alloy liners, in accordance with 7.2.5 to 7.2.7 of EN 12862:2000, and meet the requirements therein;

e) macroscopic examinations for welded stainless steel liners in accordance with 8.7 of EN 13322-2:2003/A1:2006, and meet the requirements therein;

f) when a protective coating according to 8.8 is a part of the design, a coating batch test shall be performed in accordance with B.22. Where the coating fails to meet the requirements of B.22, the batch shall be 100 % inspected to remove similarly defectively coated fuel tanks. The coating on all defectively coated fuel tanks shall be stripped using a method that does not affect the integrity of the composite wrapping and recoated. The coating batch test shall then be repeated.

For Type 4 designs, a further fuel tank, liner or sample representative of a finished fuel tank shall be subjected to the following tests:

a) verification of the critical dimensions of the design;

b) yield strength and ultimate elongation of the plastic liner material shall be determined in accordance with B.1 and meet the requirements therein;

c) softening temperature of the plastic liner shall be tested in accordance with B.4 and meet the requirements of the design;

d) when a protective coating according to 8.8 is a part of the design, a coating batch test shall be performed in accordance with B.22. Where the coating fails to meet the requirements of B.22, the batch shall be 100 % inspected to remove similarly defectively coated fuel tanks. The coating on all defectively coated fuel tanks shall be stripped using a method that does not affect the integrity of the composite wrapping and recoated. The coating batch test shall then be repeated.

All fuel tanks and liners represented by a batch test that fails to meet the requirements specified shall follow the procedures specified in 10.3.

10.2.3 Periodic ambient temperature pressure cycling test

The following tests shall be carried out on finished fuel tanks at a test frequency defined as follows:

a) initially, one fuel tank from each batch shall be pressure cycled from not more than 2 MPa to not less than 1,25 times the working pressure at a rate not to exceed 10 cycles per minute for the number of filling cycles specified in 4.5. For Type 4 designs, prior to pressure cycling, the end boss shall be torque tested in accordance with B.17, and following the required pressure cycling, the fuel tank shall be leak tested in accordance with the method specified in B.21 and meet the requirements therein;

b) if on 10 sequential production batches of a design family (i.e. similar materials and processes within the definition of a minor design change, see 9.5), none of the pressure cycled fuel tanks in a) above leak or rupture in less than 1,5 times the number of filling cycles specified in 4.5, then the pressure cycle test may be reduced to one fuel tank from every 5 batches of production;

c) if on 10 sequential production batches of a design family, none of the pressure cycled fuel tanks in a) above leak or rupture in less than 2 times the number of filling cycles specified in 4.5, then the pressure cycle test may be reduced to one fuel tank from every 10 batches of production;

d) if more than 3 months have expired since the last ambient temperature pressure cycle test, then a fuel tank from the next batch of production shall be pressure cycle tested in order to maintain the reduced frequency of batch test in b) or c) above;

e) in order to maintain a reduced frequency, all test fuel tanks shall meet the required number of pressure cycles specified in b) or c) above. Should any tested fuel tank in b) or c) above fail to meet this required number of pressure cycles, then it shall be necessary to repeat the batch pressure cycle test frequency in a) for a minimum 10 production batches in order to re-establish the reduced frequency of testing in b) or c) above.

If any fuel tank in a), b) or c) above fail to meet the minimum cycle life requirement of the number of filling cycles specified in 4.5, then the cause of failure shall be determined and corrected following the procedures in 10.3. The pressure cycle test shall then be repeated on an additional three fuel tanks from that batch. Should any of the three additional fuel tanks fail to meet the minimum pressure cycling requirement of the number of filling cycles specified in 4.5, then the batch shall be rejected. The manufacturer shall demonstrate that fuel tanks produced since the last successful batch test meet all batch test requirements.

10.3 Failure to meet batch and production test requirements

In the event of failure to meet test requirements, re-testing or re-heat treatment and re-testing shall be carried out as follows:

a) if there is evidence of a fault or an error of measurement in carrying out a test, a further test of the same kind 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 applied heat treatment, the manufacturer may subject all the metal fuel tanks or liners implicated by the failure to a further heat treatment, i.e. if the failure is in batch test, the test failure shall require re-heat treatment of all the represented metal fuel tanks or liners prior to re-testing; however, if the failure occurs sporadically in a production test, then only those metal fuel tanks or liners which fail the test shall require re-heat treatment and re-testing.

       Only the appropriate batch tests needed to prove the acceptability of the new batch shall be performed again. If one or more tests prove unsatisfactory, all metal fuel tanks or liners of the batch shall be rejected.

    2) If the failure is due to a cause other than the heat treatment applied, all defective metal fuel tanks or liners shall be either rejected or repaired. Repaired metal fuel tanks or liners that pass the test(s) required for the repair shall be treated as a separate new batch.

11 Markings

On each fuel tank, the manufacturer shall provide clear, permanent markings. The font size used on the markings shall be a minimum of 5 mm high on fuel tanks with a diameter greater than or equal to 140 mm and greater than 2,5 mm high on fuel tanks with a diameter of less than 140 mm. Marking shall be made either by labels incorporated into resin coatings, labels attached by adhesive, low stress stamps used on the thickened ends of Type 1 and Type 2 designs or any combination of the above. Adhesive labels and their application shall be in accordance with ISO 7225. Multiple labels may be used and should be located such that they are not obscured by mounting brackets.

Each fuel tank shall be permanently marked with the following information:

a) "H_2 ONLY" or "CNG-H_2 BLENDS ONLY" or "H_2 OR CNG-H_2 BLENDS ONLY";

b) "DO NOT USE AFTER XXXX-XX", where XXXX-XX identifies the year and the month of expiry;

c) manufacturer's identification;

d) fuel tank identification (a serial number unique for every fuel tank*)*;

e) water capacity (l);

f) reference to this International Standard, "ISO 15869:2009", and the type of fuel tank;

g) "USE ONLY MANUFACTURER-APPROVED NON-RECLOSING THERMALLY ACTIVATED PRESSURE RELIEF DEVICE";

h) date of manufacture (year in four digits and month in two digits);

i) working pressure (MPa) at temperature (°C);

j) if labels are used, there is an additional requirement for a unique identification number and the manufacturer's identification to be permanently marked on an exposed metal surface in order to permit tracing in the event that the label is destroyed;

k) if the fuel tank has a reduced number of filling cycles according to 4.5.2, and qualified according to 9.2, then the fuel tank shall additionally be marked "USE ONLY WITH TAMPER-PROOF FILLING CYCLE COUNTER SYSTEM";

l) if the fuel tank is qualified according to 9.5 for permanently mounted use in on-road four-wheel passenger vehicles, the fuel tank shall additionally be marked "FUEL TANK SERVICE LIFE ENDS AFTER USE IN A SINGLE VEHICLE. FUEL TANK TRANSFER BETWEEN VEHICLES IS PROHIBITED".

The expiry date may be applied to the fuel tanks at the time of dispatch, provided that the fuel tanks have been stored in a dry location without internal pressure. The period between the dispatch date and the expiry date shall not exceed the specified service life.

The markings shall be placed in the listed sequence, but the specific arrangement may be varied to match the space available. The following is an acceptable example.

H_2 or CNG-H_2 BLENDS ONLY
DO NOT USE AFTER 2020-03
Manufacturer/Fuel tank identifications
140 l
ISO 15869:2009, Type 3
USE ONLY MANUFACTURER-APPROVED NON-RECLOSING THERMALLY ACTIVATED PRESSURE RELIEF DEVICE
Manufacture date 2005-03
35 MPa/15 °C

12 Preparation for dispatch

Prior to dispatch from the manufacturer, every fuel tank shall be internally clean and dry. Fuel tanks not immediately closed by the fitting of a valve and safety devices, if applicable, shall have plugs fitted to all openings to prevent the entry of moisture and protect threads. Each fuel tank shall be checked for appropriate markings.

The manufacturer's statement of service and all necessary information and instructions to ensure the proper handling, use and in-service inspection of the fuel tank shall be supplied. The statement of service shall be in accordance with 5.2.

Annex A
(informative)

Rationale for number of filling cycles

A.1 Personal vehicles

A.1.1 General

The number of filling cycles that a fuel tank should be capable of performing requires consideration of two scenarios of risk for material and system degradation: expected service and extended durability as shown in A.1.2 and A.1.3.

A.1.2 Expected service

The extreme stress case where the vehicle sustains only the most stressful (empty-to-full) fillings throughout its entire lifetime should be considered.

The maximum number of empty-to-full fillings in expected service is given by the following equation:

$$F_\mathrm{f} = (L/R)$$

where

F_f is the maximum number of empty-to-full fillings in expected service;

L is the vehicle lifetime mileage in the expected service scenario;

R is the vehicle driving range with a full fuel tank.

Fuel tanks are required to demonstrate the capability to sustain this maximum number of lifetime empty-to-full filling events.

Under no circumstances should the maximum number of empty-to-full fillings in expected service be allowed to be less than 500 empty-to-full fillings as specified in E.3.2, which is based on a vehicle lifetime mileage of 161 000 km and a vehicle driving range with a full fuel tank of 322 km.

A.1.3 Extended durability

The high usage case, where the vehicle sustains exposure to more severe (physical and chemical) environmental stresses and experiences a higher number of partial fillings throughout its entire lifetime, should also be considered.

Environmental stresses include abrasions and cuts associated with wear from vehicle attachments and from chemical exposures to chemically active constituents encountered in service (e.g. acid rain slush, battery acid).

Fuel tanks are required to demonstrate the capability to sustain a maximum number of lifetime partial filling events.

The maximum number of partial fillings is given by the following equation:

$$F_{\mathrm{P}} = \left(\frac{L}{R \times V} \right)$$

where

F_{P} is the maximum number of partial fillings in service;

L is the vehicle lifetime mileage in extended durability scenario;

R is the vehicle driving range with a full fuel tank;

V is the average fill volume fraction.

The reduced number of 5 500 filling cycles specified in 4.5.2 is based on the following assumptions:

— a vehicle lifetime mileage in extended durability scenario of 590 000 km;

— a vehicle driving range with a full fuel tank of 322 km;

— an average fill volume fraction of 0,33.

An evaluation by the Sierra Research for the California Air Resource Board (2001) of vehicle lifetime mileage showed all scrapped vehicles had mileage below 563 000 km (the 3-sigma value, the 99.8^{th} percentile, was 418 000 km; the 6-sigma value was 590 000 km). This is why the value of 590 000 km was selected for the vehicle lifetime mileage in extended durability scenario.

At present, all on-road vehicles produced by high volume vehicle manufacturers have a vehicle range with a full fuel tank greater than 322 km.

Reliable statistics on current fill volume fraction are not available; statistics for hydrogen-fuelled vehicles will be influenced by the availability of hydrogen refuelling stations. The assumption was based on the fact that a lifetime of fillings needing less than 33% of full fuel tank capacity provides a high-frequency extreme associated with a lifetime average of fillings on intervals of 106 km to 161 km travelled.

Compounding these extremes gives a conservative requirement for the minimum reduced number of filling cycles specified in 4.5.2 for extended durability.

A.1.4 Robustness (safety margin) of extended durability design-qualification requirement

The probability of a fuel tank encountering the specified number is fillings is given by the multiplication of the probability that the vehicle lifetime mileage exceeds or is equal to 590 000 km (Prob_1) by the probability of having a vehicle driving range with a full fuel tank equal to or less than 322 km (Prob_2) by the probability of having an average fill volume fraction of 0,33 for the vehicle lifetime (Prob_3). Estimates from data cited above indicate that Prob_1 and Prob_2 are each lower than 10^{-6}, ensuring that the result is below 10^{-12}.

A vehicle with a modest driving range of 322 km with a full fuel tank would have to be driven over 1 600 000 km to require 5 500 empty-to-full fillings.

Low-volume partial fills cause markedly lower swings in temperature and pressure and, consequently, markedly lower stresses than empty-to-full filling stresses. Comprehensive data is not available (stresses an order of magnitude lower than empty-to-full fillings have been seen). Therefore, conducting the high-frequency filling pressure cycle tests using the reduced number of filling cycles specified in 4.5.2 with empty-to-full filling pressure swings provides a margin of robustness potentially in the order of 10.

A.2 Commercial heavy-duty vehicles

Two factors distinguish the design qualification of fuel tanks for commercial heavy-duty (high usage) service.

Firstly, commercial fleet vehicles may experience extensive maintenance (such as engine and transmission overhauls) that significantly extend the vehicle lifetime mileage (vehicle range) and thereby increase the number of fillings during expected service.

Secondly, commercial fleet vehicles commonly remain in high-usage service for periods of 15 years or more. Fleet managers have requested certification of storage systems for 20 to 25 years of service life. Additionally, commercial fleet vehicles may routinely experience daily empty-to-full fillings followed by immediate (overnight) parking such that the fuel pressure and temperature are not immediately relieved by subsequent driving.

Reflecting these differences, the requirements for pressure cycle testing for commercial heavy-duty vehicles assume the following:

— The maximum number of empty-to-full fillings in expected service should be calculated using the equation given in A.1.2; however, this value may not be less than 1 000 cycles. This provides for commercial vehicles with twice the vehicle lifetime mileage in the expected service scenario of personal vehicles. If firm statistics on commercial vehicle lifetime mileage become available, this value may be revised in future editions of this document.

— In the extended durability scenario, the number of filling cycles should be calculated as according to the equation defined in A.1.3, but it should not be less than 11 250. In order to allow for unconstrained usage per year, the extreme condition of 2 empty-to-full fillings per day were assumed for continual full-day bus service. The minimum certification for commercial vehicles is specified as 15 years; hence, the minimum number of filling cycles is 2 empty-to-full fillings per day × 365 days per year × 15 years = 11 000. The robustness of this specification is assured by recognition that 11 000 filling cycles × 322 km/filling cycle exceeds 3,2 million km driven.

Annex B
(normative)

Test methods and acceptance criteria

B.1 Coating tests

Coatings shall be evaluated in accordance with the following procedure:

a) adhesion testing in accordance with ISO 4624. A minimum rating of 4 shall be obtained when measured using Method A or B, as appropriate;

b) flexibility in accordance with ASTM D 522, using Test Method B with a 12,7 mm mandrel at the specified thickness at − 20 °C. Samples for the flexibility test shall be prepared in accordance with ASTM D 522. There shall be no visually apparent cracks;

c) impact resistance in accordance with ASTM D 2794. The coating at room temperature shall pass a forward impact test of 18 J;

d) chemical resistance in accordance with ASTM D 1308 except as identified in the following. The tests shall be conducted using the open spot test method and 100-hour exposure to a 30 % sulphuric acid solution (battery acid with specific gravity of 1,219) and 24-hour exposure to a polyalkalene glycol (e.g. brake fluid). There shall be no evidence of lifting, blistering or softening of the coating. The adhesion shall meet a rating of 3 when tested in accordance with ISO 4624;

e) light and water exposure using a UVA-340 lamp in accordance with ASTM G 154 for a minimum of 1 000 hours. There shall be no evidence of blistering, and adhesion shall meet a rating of 3 when tested in accordance with ISO 4624. The maximum gloss loss shall be less than or equal to 20 %;

f) salt spray exposure in accordance with ASTM B 117 for a minimum 500 hours. Undercutting shall not exceed 3 mm at the scribe mark. There shall be no evidence of blistering, and adhesion shall meet a rating of 3 when tested in accordance with ISO 4624;

g) resistance to chipping at room temperature in accordance with ASTM D 3170. The coating shall have a rating of 7A or better, and there shall be no exposure of the substrate.

B.2 Hydrogen compatibility tests

Hydrogen compatibility of the fuel tank or liner material shall be demonstrated by one of the following:

a) using a material known to be resistant to hydrogen embrittlement under the prevailing service conditions, for example as specified in ISO 11114-1 or ISO/TR 15916;

b) demonstrating the hydrogen compatibility of the material in accordance with ISO 11114-4 or an equivalent comparative test method for resistance to sustained hydrogen loading and performing a fatigue test in a hydrogen environment. An example of an acceptable fatigue test includes the hydrogen gas cycle testing of a complete liner between the pressure levels that provide an equivalent liner wall stress as would be present in the fuel tank at 2 MPa and 1,25 times the working pressure; or

c) by conducting hydrogen pressure cycle tests with a complete fuel tank from 2 MPa to 1,25 times the working pressure. The fuel tank shall not fail before reaching the number of filling cycles as specified according to 4.5.

In all cases, the reduction of cycle life due to the effect of hydrogen exposure shall be considered.

B.3 Tensile properties of plastics

For Type 4 designs, the tensile yield strength and ultimate elongation of plastic liner material shall be determined at – 40 °C in accordance with ISO 527-2.

The test results shall demonstrate the ductile properties of the plastic liner material at temperatures of – 40 °C or lower by meeting the values specified by the manufacturer.

B.4 Softening temperature of plastics

For Type 4 designs, polymeric materials from finished liners shall be tested in accordance with ISO 306. The appropriate method to be applied should be specified by the supplier of the polymeric material.

The softening temperature shall be at least 100 °C.

B.5 Resin properties tests

For Type 2, Type 3 and Type 4 designs, resin shear strength shall be tested on three sample coupons representative of the composite over-wrap in accordance with ASTM D 2344. Following a 24-hour water boil, the composite shall have a minimum shear strength of 13,8 MPa.

For Type 2, Type 3 and Type 4 designs, resin glass transition temperature shall be determined in accordance with ASTM D 3418 or equivalent. The test results shall be within the manufacturer’s specifications.

B.6 Hydrostatic burst pressure test

The fuel tank shall be filled with a fluid such as water and the pressure gradually increased until failure of the fuel tank. It shall be ensured that the pressure measuring device is monitoring the true fuel tank pressure, particularly when the pressurization rate exceeds 0,35 MPa/s. Alternatively, there shall be a five second hold at the minimum design burst pressure.

The burst pressure shall be recorded. Unless different burst test criteria are specified for different test methods, the actual fuel tank burst pressure shall exceed the minimum burst pressure given in Table 1 for the applicable fuel tank design. In no case shall the burst pressure be less than the value necessary to meet the stress ratio requirements in Table 1. A leak or rupture may occur in either the cylindrical region or the dome region of the fuel tank.

B.7 Ambient temperature pressure cycling

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

a) fill the fuel tank with a non-corrosive fluid such as oil, inhibited water or glycol;

b) cycle the pressure in the fuel tank between not more than 2 MPa and not less than 1,25 times the working pressure at a rate not to exceed 10 cycles per minute.

The fuel tank shall be pressure cycled until failure or to a minimum of 3 times the number of filling cycles specified in 4.5. The fuel tanks shall not fail before reaching the number of filling cycles specified in 4.5. Fuel tanks exceeding the number of filling cycles specified in 4.5 shall fail by leakage and not by rupture. If failure occurs, the number of cycles to failure shall be reported, along with the location and description of the failure initiation.

Fuel tanks achieving 3 times the number of filling cycles specified in 4.5 without failure need not perform the leak-before-break (LBB) test in B.8.

B.8 Leak-before-break (LBB) test

The fuel tank shall be filled with a non-corrosive fluid such as oil, inhibited water or glycol and hydraulically pressure cycled from not more than 2 MPa to not less than 1,5 times the working pressure at a maximum rate of 10 cycles per minute. The fuel tank shall fail by leakage or shall exceed the number of filling cycles specified in 4.5.

B.9 Bonfire test

B.9.1 General

The bonfire test is designed to demonstrate that finished fuel tanks, complete with the fuel tank manufacturer specified fire protection system, will not rupture when tested under specified fire conditions.

Precautions shall be taken during fire testing in the event that a fuel tank rupture occurs.

B.9.2 Set-up

The fuel tank shall be placed horizontally with the fuel tank bottom approximately 100 mm above the fire source.

Metallic shielding of at least 0,4 mm thickness shall be used to prevent direct flame impingement on fuel tank valves, fittings and/or pressure relief devices. The metallic shielding shall not be in direct contact with the fuel tank manufacturer specified non-reclosing thermally activated pressure relief devices.

Any failure during the test of a valve, fitting or tubing that is not part of the fuel tank manufacturer specified fire protection system shall invalidate the result.

B.9.3 Fire source

A uniform fire source of 1,65 m in length shall provide direct flame impingement on the fuel tank surface across its entire diameter (width).

Any fuel may be used for the fire source provided it supplies uniform heat sufficient to maintain the specified test temperatures until the fuel tank is vented. The selection of a fuel should take into consideration air pollution concerns. The arrangement of the fire shall be recorded in detail to ensure the rate of heat input to the fuel tank is reproducible.

Any failure or inconsistency of the fire source during a test shall invalidate the result.

B.9.4 Temperature and pressure measurements

Surface temperatures shall be monitored by at least three thermocouples located on the bottom surface of the fuel tank and spaced not more than 0,75 m apart.

Metallic shielding of 0,4 mm minimum thickness shall be used to prevent direct flame impingement on the thermocouples. Thermocouple temperatures and the fuel tank pressure shall be recorded at intervals of every ten seconds or less during the test.

B.9.5 General test requirements

The fuel tank shall be pressurized to the working pressure with hydrogen or hydrogen blend applicable to the design and tested in the horizontal position.

Following ignition, the fire shall produce flame impingement on the surface of the fuel tank along the 1,65 m length of the fire source and across the fuel tank diameter.

Within 5 minutes of ignition, the temperature of at least one thermocouple shall indicate a minimum temperature of 590 °C. This minimum temperature shall be maintained for the remaining duration of the test.

For fuel tanks of length of 1,65 m or less, the centre of the fuel tank shall be positioned over the centre of the fire source.

For fuel tanks of length greater than 1,65 m, the fuel tank shall be positioned in accordance with the following procedure:

a) if the fuel tank is fitted with a non-reclosing thermally activated pressure relief device at one end, the fire source shall commence at the opposite end of the fuel tank;

b) if the fuel tank is fitted with non-reclosing thermally activated pressure relief devices at both ends, or at more than one location along the length of the fuel tank, the centre of the fire source shall be centred midway along the longest fuel tank span without non-reclosing thermally activated pressure relief devices;

c) if the fuel tank is additionally protected with thermal insulation, two fire tests at the working pressure shall be performed, one with the fire centred midway along the fuel tank length with the non-reclosing thermally activated pressure relief devices removed, and the other with the fire commencing at one of the ends of a second fuel tank with the non-reclosing thermally activated pressure relief devices installed. If necessary to ensure minimum bonfire temperatures are achieved during the test, the thermocouples on the bottom surface of the fuel tank shall instead be placed on the bottom external surface of the thermal insulation.

B.9.6 Acceptable results

The fuel tank shall vent through the non-reclosing thermally activated pressure relief device, part of the fuel tank manufacturer specified fire protection system. If the fuel tank vents through a fitting or valve other than this non-reclosing thermally activated pressure relief device, the test shall be repeated.

For fuel tanks that are additionally protected with a thermal insulation, when the thermal insulation alone is tested under B.9.5 c), the fuel tank shall not fail when exposed to a bonfire of 20 minutes duration.

The results shall summarize the elapsed time from ignition of the fire to the start of venting through non-reclosing thermally activated pressure relief device(s) and the maximum pressure and time of evacuation until a pressure of less than 1 MPa is reached.

B.10 Penetration test

A fuel tank pressurized to the working pressure ± 1 MPa with compressed hydrogen gas shall be penetrated by an armour piercing bullet or impactor with a diameter of 7,62 mm or greater. The bullet shall completely penetrate at least one sidewall of the fuel tank. The bullet or impactor shall impact the sidewall at an approximate angle of 45° to the fuel tank centreline. The fuel tank shall not rupture.

For fuel tank designs to be used with hydrogen blends, the design shall also meet the requirements of the penetration test in accordance with ISO 11439 for natural gas.

B.11 Chemical exposure test

The following chemical exposure test procedure shall be performed on a finished fuel tank, including the coating if applicable:

a) The upper section of the fuel tank shall be divided into five distinct areas and marked for pendulum impact preconditioning and fluid exposure (see Figure B.1). The five areas shall each be nominally 100 mm in diameter. The five areas do not need to be oriented along a single line, but they shall not overlap.

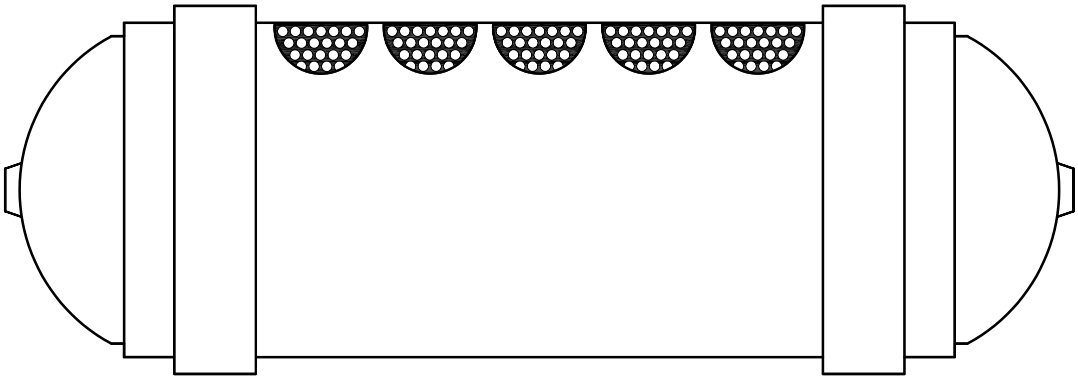

Figure B.1 — Fuel tank orientation and layout of exposure areas

b) The approximate centre of each of the five areas shall be preconditioned by the impact of a pendulum body. The steel impact body of the pendulum shall have the shape of a pyramid with equilateral triangle faces and a square base, the summit and the edges being rounded to a radius of 3 mm. The centre of percussion of the pendulum shall coincide with the centre of gravity of the pyramid; its distance from the axis of rotation of the pendulum being 1 m and the total mass of the pendulum referred to its centre of percussion shall be 15 kg. The energy of the pendulum at the moment of impact shall not be less than 30 J. During pendulum impact, the fuel tank shall be held in position by the end bosses or by the intended mounting brackets. The fuel tank shall not be under pressure during preconditioning.

c) Each of the five preconditioned areas shall be exposed to one of five solutions (each solution shall be used and applied to only one preconditioned area). The five solutions are the following:

- volume fraction of 19 % sulphuric acid in water;
- mass fraction of 25 % sodium hydroxide in water;
- volume fraction of 5 % methanol in gasoline;
- mass fraction of 28 % ammonium nitrate in water;
- volume fraction of 50 % methyl alcohol in water (i.e. windscreen washer fluid).

During the exposure, orient the test cylinder with the fluid exposure areas on top. Place a pad of glass wool approximately 0,5 mm thick and 100 mm in diameter on each of the five preconditioned exposure areas. Apply an amount of the test fluid to the glass wool sufficient to ensure that the pad is wetted evenly across its surface and through its thickness for the duration of the test.

d) The fuel tank shall then be filled with a non-corrosive fluid such as oil, inhibited water or glycol and hydraulically pressure cycled from not more than 2 MPa to not less than 1,25 times the working pressure for at least 0,6 times the number of filling cycles specified in 4.5. After pressure cycling, the fuel tank shall be pressurized to 1,25 times the working pressure and held at that pressure for a minimum of 24 hours.

e) When burst tested in accordance with B.6, the fuel tank shall have a burst pressure that exceeds 1,8 times the working pressure.

B.12 Composite flaw tolerance tests

The finished fuel tank, complete with any protective coating, shall have flaws in the longitudinal direction cut into the composite. The flaws shall be greater than the visual inspection limits specified by the manufacturer. As a minimum, one flaw shall be 25 mm long and 1,25 mm in depth, and another flaw shall be 200 mm long and 0,75 mm in depth, cut in the longitudinal direction into the fuel tank sidewall.

The flawed fuel tank shall then be filled with a non-corrosive fluid such as oil, inhibited water or glycol and pressure cycled from not more than 2 MPa to not less than 1,25 times the working pressure at ambient temperature for the number of filling cycles specified in 4.5.

The fuel tank shall not leak or rupture within the first 0,2 times the number of filling cycles specified in 4.5, but may fail by leakage during the last 0,8 times the number of filling cycles specified in 4.5.

B.13 Accelerated stress rupture test

The fuel tank shall be hydrostatically pressurized to 1,25 times the working pressure at 85 °C. The fuel tank shall be held at this pressure and temperature for 1 000 hours. The fuel tank shall then be pressured to burst in accordance with the procedure specified in B.6, except that its burst pressure shall exceed 80 % of the average of the results obtained during the hydrostatic burst test of 9.2.7.

B.14 Extreme temperature pressure cycling

The finished fuel tank, with the composite wrapping free of any protective coating, shall be cycle tested in accordance with the following procedure:

a) Fill with a non-corrosive fluid such as oil, inhibited water or glycol and condition for 48 hours at a pressure of less than 2 MPa, a temperature of not less than 85 °C and 95 % or greater relative humidity. The intent of this requirement shall be deemed met by spraying with a fine spray or mist of water in a chamber held at 85 °C.

b) Hydrostatically pressurize for 0,5 times the number of filling cycles specified in 4.5 between not more than 2 MPa nor less than 1,25 times the working pressure at 85 °C or higher as measured on the fuel tank surface and 95 % or greater relative humidity.

c) Condition the fuel tank and fluid at –40 °C or lower as measured in the fluid and on the fuel tank surface.

d) Pressurize from not more than 2 MPa to not less than the working pressure for 0,5 times the number of filling cycles specified in 4.5, at –40 °C or lower. For Type 4 designs, recording instrumentation shall be provided to ensure the minimum temperature of the fluid is maintained during the low temperature cycling.

The pressure cycling rate of b) shall not exceed 10 cycles per minute. The pressure cycling rate of d) shall not exceed 2 cycles per minute unless a pressure transducer is installed directly within the fuel tank.

During this pressure cycling, the fuel tank shall show no evidence of rupture, leakage or fibre unravelling.

Following pressure cycling at extreme temperatures, fuel tanks shall be hydrostatically pressured to failure in accordance with B.6 and achieve a minimum burst pressure that exceeds 80 % of the average of the results obtained during the hydrostatic burst test of 9.2.7.

B.15 Impact damage test

One or more finished fuel tanks shall be drop tested at ambient temperature without internal pressurization or attached valves. All drop tests may be performed on one fuel tank, or individual impacts on a maximum of 3 fuel tanks. A plug may be inserted in the threaded ports to prevent damage to the threads and seal surfaces.

The surface onto which the fuel tanks are dropped shall be a smooth horizontal concrete pad or similar rigid surface. The fuel tank(s) shall be tested in accordance with the following procedure:

a) drop once from a horizontal position with the bottom 1,8 m above the surface onto which it is dropped;

b) drop once onto each end of the fuel tank from a vertical position with a potential energy of not less than 488 J, but in no case shall the height of the lower end be greater than 1,8 m;

c) drop once at a 45° angle, and then for non-symmetrical and non-cylindrical fuel tanks, rotate the fuel tank through 90° along its longitudinal axis and drop again at 45°, with its centre of gravity 1,8 m above the impact surface. However, if the bottom is closer to the impact surface than 0,6 m, the drop angle shall be changed to maintain a minimum height of 0,6 m and a centre of gravity of 1,8 m above the impact surface.

No attempt shall be made to prevent the bouncing of fuel tanks, but the fuel tanks may be prevented from falling over during the vertical drop test described in b).

Following the drop impact, the fuel tanks shall then be filled with a non-corrosive fluid such as oil, inhibited water or glycol and pressure cycled from not more than 2 MPa to not less than 1,25 times the working pressure at ambient temperature for the number of filling cycles specified in 4.5. The fuel tank(s) shall not leak or rupture within 0,2 times the number of filling cycles specified in 4.5, but may fail by leakage during the remaining test cycles.

B.16 Permeation test

For Type 4 designs, the finished fuel tank shall be filled with compressed hydrogen to working pressure, placed in a sealed chamber at ambient temperature and monitored for permeated flow for 500 hours. The steady state permeation rate for hydrogen gas shall be less than 2,00 cm^3 of hydrogen per hour according to litre water capacity at 35 MPa, and 2,8 cm^3 per hour according to litre water capacity at 70 MPa. At working pressures other than those stated, the permeation rate should be interpolated or extrapolated based on the above permissible permeation rates.

Other permeation limits may be specified by the fuel tank manufacturer for specific applications where the permeation of hydrogen will not cause a hazard.

B.17 Boss torque test

The body of the fuel tank shall be restrained against rotation and a torque specified by the manufacturer shall be applied to each end boss of the fuel tank. The torque shall be applied first in the direction to tighten a threaded connection, then in the loosening direction, and finally again in the tightening direction.

The fuel tank shall then be subjected to a leak test in accordance with B.21, followed by a burst test in accordance with B.6.

B.18 Hydrogen gas cycling test

Special consideration shall be given to safety when conducting this test. Prior to conducting this test, fuel tanks of the same design shall have successfully passed the test requirements of B.6 (hydrostatic burst pressure test), B.7 (ambient temperature pressure cycling) and B.16 (permeation test). The fuel tank to be used in the test shall have successfully passed the test requirements of B.20 (hydraulic test).

The finished fuel tank shall be pressure cycled using compressed hydrogen gas from less than 2 MPa to not more the working pressure for 1 000 cycles, or for the number of filling cycles specified in 4.5. The filling time shall be less than or equal to five minutes, and the total cycle time shall be less than or equal to one hour. Every 100 cycles, there shall be a 24-hour hold period at the working pressure.

Unless otherwise specified by the manufacturer, temperatures during the test shall be monitored using a thermocouple attached to the metal end boss at both ends of the fuel tank. If only one boss end is exposed, the second temperature shall be obtained by inserting a probe into the fuel tank to measure the gas temperature at the opposite end. Care shall be taken to ensure that temperatures during filling and venting do not exceed the defined service conditions.

For Type 4 fuel tanks subjected to the 1 000 cycles, following completion of the hydrogen gas cycling, the fuel tank shall be leak tested in accordance with B.21, then sectioned and the plastic liner and liner/end boss interface inspected for evidence of any deterioration, such as fatigue cracking or electrostatic discharge. If there is evidence of deterioration, another fuel tank of the same design shall be hydrogen gas cycle tested for the number of filling cycles specified in 4.5 without failure.

For Type 4 designs to be used with hydrogen blends, the design shall also meet the requirements of the natural gas cycle test in accordance with ISO 11439.

B.19 Hardness test

Hardness tests shall be carried out on the parallel wall at the centre and at one of the domed ends of each fuel tank or liner in accordance with ISO 6506-1 or using an equivalent method. The test shall be carried out after the final heat treatment, and the hardness values thus determined shall be in the range specified for the design.

B.20 Hydraulic test

Any internal pressure applied after auto-frettage and prior to the hydraulic test shall not exceed 90 % of the hydraulic test pressure.

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

a) the fuel tank shall be hydraulically tested to at least 1,5 times the working pressure. In no case shall the test pressure exceed the auto-frettage pressure;

b) pressure shall be maintained for 30 seconds or sufficiently longer to ensure complete expansion. If the test pressure cannot be maintained due to failure of the test apparatus, the test shall be repeated at a pressure increased by 0,7 MPa. No more than two such repeat tests shall be performed;

c) fuel tanks not meeting the defined limit of permanent volumetric expansion or elastic expansion specified by the fuel tank manufacturer shall be rejected and rendered unserviceable.

B.21 Leak test

Fuel tank designs shall be leak tested in accordance with the following procedure:

a) thoroughly dry the fuel tank;

b) pressurize the fuel tank to working pressure with hydrogen or dry air or nitrogen containing a detectable gas such as helium.

Any leakage detected shall be cause for rejection.

NOTE Leakage is the release of gas through a crack, pore, unbond or similar defect. Permeation through the wall in conformity to B.16 is not considered to be leakage.

B.22 Coating batch tests

B.22.1 Coating thickness

The thickness of the coating shall be measured in accordance with ISO 2808 and shall meet the requirements of the design.

B.22.2 Coating adhesion

The coating adhesion strength shall be measured in accordance with ISO 4624 and shall have a minimum rating of 4 when measured using either test method A or B, as appropriate.

Annex C
(informative)

Verification of stress ratios using strain gauges

The following describes a procedure that may be used to verify stress ratios by using strain gauges.

a) Stress-strain relationship for fibres is always elastic; therefore, stress ratios and strain ratios are equal.

b) High elongation strain gauges are required.

c) Strain gauges should be oriented in the direction of the fibres on which they are mounted (i.e. with hoop fibre on the outside of the fuel tank, mount gauges in the hoop direction).

d) Method 1 (applies to fuel tanks that do not use high tension winding):

   1) prior to auto-frettage, apply strain gauges and calibrate;

   2) measure strains at auto-frettage pressure, zero pressure after auto-frettage, working pressure and minimum burst pressure;

   3) confirm that the strain at minimum burst pressure divided by the strain at working pressure meets the stress ratio requirements. For hybrid construction, the strain at working pressure is compared with the rupture strain of fuel tanks reinforced with a single fibre type.

e) Method 2 (applies to all fuel tanks):

   1) at zero pressure after winding and auto-frettage, apply strain gauges and calibrate;

   2) measure strains at zero pressure, working pressure and minimum burst pressure;

   3) at zero pressure, after strain measurements are taken at working pressure and minimum burst pressure and with strain gauges monitored, cut the fuel tank section apart so that the region containing the strain gauge is approximately 125 mm long. Remove the liner without damaging the composite. Measure the strains after the liner is removed;

   4) adjust the strain readings at zero pressure, working pressure and minimum burst pressure by the amount of strain measured at zero pressure with and without the liner;

   5) confirm that the strain at minimum burst pressure divided by the strain at working pressure meets the stress ratio requirements. For hybrid construction, the strain at working pressure is compared with the rupture strain of fuel tanks reinforced with a single fibre type.

Annex D
(informative)

NDE defect size by flawed fuel tank cycling

The following procedure can be used to determine the non-destructive examination (NDE) defect size for designs.

a) Introduce internal and external flaws. Internal flaws may be machined prior to the heat treatment and closing of the end of the fuel tank.

b) Size these artificial defects to exceed the defect length and depth detection capability of the NDE inspection method.

c) Pressure cycle three fuel tanks containing these artificial defects to failure in accordance with the test method specified in B.7.

If the fuel tanks do not leak or rupture in less than the number of filling cycles specified in 4.5, then the allowable defect size for NDE is equal to or less than the artificial flaw size at that location.

In all cases, the reduction of cycle life due to the effect of hydrogen exposure should be considered.

Annex E
(normative)

Alternative type tests

E.1 General

These tests, designed to be performed on hydrogen storage systems, are intended to demonstrate the suitability of fuel tanks for application as a permanent mounted fuel storage system in on-road four-wheel passenger vehicles. Based on the manufacturer's designation of the intended vehicle use, the fuel tanks shall be qualified for personal vehicle use or commercial heavy-duty vehicle use.

One fuel tank shall be subjected to the series of tests listed in Table E.1 in the sequence specified in E.2.

Table E.1 — Individual tests

E.3	Extreme temperature gas pressure cycle test (Fuelling/De-Fuelling)
E.4	Accelerated static stress test (Parking)
E.5	Leak/permeation test
E.6	Proof pressure test
E.7	Residual strength burst test

E.2 Test sequence

Half of the extreme temperature gas pressure cycle test specified in E.3 (50 % of the pressure cycles defined in E.3.2) shall be conducted before the start of the accelerated static stress test (E.4).

The remaining extreme temperature gas pressure cycle test specified in E.3 (the remaining 50 % of the pressure cycles defined in E.3.2) shall be conducted after the first 500-hour exposure in the accelerated static stress test (E.4).

The first 500 hours of the accelerated static stress test (E.4) shall be performed after the first half of the extreme temperature gas pressure cycle test specified in E.3 (50 % of the pressure cycles defined in E.3.2) has been conducted. The remaining 500 hours of exposure shall occur after the completion of the extreme temperature gas pressure cycle test (E.3).

The leak/permeation test (E.5), the proof pressure test (E.6) and the residual strength burst test (E.7) shall be conducted in that order on the fuel tank after the completion of the extreme temperature gas pressure cycle test (E.3) and the accelerated static stress test (E.4). The leak/permeation test may be conducted in conjunction with the final 500 hours of the accelerated static stress test (E.4).

E.3 Extreme temperature gas pressure cycle test

E.3.1 Pressure cycles

The fuel tank shall be pressure cycled using compressed hydrogen gas from less than 2 MPa to not more than 1,25 times the working pressure for the number of filling cycles specified in E.3.2. All of the simulated fillings shall occur under normal fast-fill conditions specified by the vehicle manufacturer. All simulated discharges shall occur at a rate of not less than the discharge rate for maximum-load vehicle operation as specified by the vehicle manufacturer.

E.3.2 Number of pressure cycles

The number of pressure cycles that the fuel tank shall be subjected to during the extreme temperature gas pressure cycle test shall be representative of the maximum number of empty-to-full fillings in expected service and calculated as follows:

$$F_\mathrm{f} = \left(L/R\right)$$

where

F_f is the maximum number of empty-to-full fillings in expected service;

L is the vehicle lifetime mileage in the expected service scenario;

R is the vehicle driving range with a full fuel tank.

In no case shall the number of pressure cycles be less than 500 for fuel tanks qualified for personal vehicle use (see Annex A). In the case of fuel tanks qualified for commercial heavy-duty vehicle use, the minimum number of pressure cycles shall not be less than 1 000 (see Annex A).

E.3.3 Description of test

The first 25 % of the number of pressure cycles specified in E.3.1 and in E.3.2 shall be conducted with hydrogen gas at –35 °C or lower in an external environment stabilized at –40 °C. If the manufacturer restricts fuel tank use to a different lower ambient temperature, then that specified lower temperature shall be used.

The fuel tank shall be equilibrated at full fill density at –40 °C at the onset and between each of the first ten pressure cycles. Hydrogen gas at 20 °C shall be used for fuelling in the first 5 equilibrated pressure cycles. Hydrogen gas at –35 °C or lower shall be used for fuelling in the next 5 equilibrated pressure cycles and for fuelling in the remaining cycles, which are not equilibrated.

The second 25 % of the number of pressure cycles specified in E.3.1 and in E.3.2 shall be conducted with hydrogen gas at –35 °C or lower in an external environment stabilized at 50 °C and 95 % relative humidity. At least 50 of the simulated discharges shall occur at the rate prescribed in the vehicle manufacturer's procedures for vehicle maintenance/repair service. The fuel tank shall be equilibrated unfilled at 50 °C and 95 % relative humidity at the onset and between each of the first five cycles conducted at 50 °C.

The third 25 % of the number of pressure cycles specified in E.3.1 and in E.3.2 shall be conducted with hydrogen gas at –35 °C or lower in an external environment stabilized at 50 °C and 95 % relative humidity.

The final 25 % of the number of pressure cycles specified in E.3.1 and in E.3.2 shall be conducted with hydrogen gas at –35 °C or lower in an external environment stabilized at –40 °C, unless a different temperature limit for vehicle use is specified by the vehicle manufacturer.

The fuel tank shall not leak or rupture during the test.

E.4 Accelerated static stress test

The fuel tanks that are being qualified for personal vehicle use shall be pressurized with hydrogen gas to 1,25 times the working pressure and held for a total of 1 000 hours at 85 °C. Fuel tanks that are being qualified for commercial heavy-duty vehicle use shall be pressurized with hydrogen gas to 1,35 times the working pressure.

E.5 Leak/permeation test

The fuel tank shall be pressurized with hydrogen gas to at least working pressure in an enclosure to determine that the steady state hydrogen discharge rate due to leakage and permeation does not exceed 75 cm^3/min (at 20 °C and 101,325 kPa) for use in standard passenger cars. For fuel tanks to be used in larger vehicles, such as buses, the allowable leakage may be increased in proportion to the enclosure volume for the vehicle. This test may be conducted coincidentally with the last half of the accelerated static stress test in E.4.

E.6 Proof pressure test

The fuel tank shall be pressurized with hydrogen gas to 1,8 times the working pressure and held 30 seconds without burst. This test may be performed hydraulically.

E.7 Residual strength burst test (hydraulic)

The fuel tank shall be pressurized hydraulically to burst to verify that the burst pressure exceeds 90 % of the average burst pressures obtained during the hydrostatic burst tests of 9.2.7.

Bibliography

[1] ISO 11114-1, *Transportable gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 1: Metallic materials*

[2] ISO/TR 15916, *Basic considerations for the safety of hydrogen systems*

[3] ANSI/AIAA G-095-2004, *AIAA Guide to Safety of Hydrogen and Hydrogen Systems*

[4] ANSI/IAS PRD 1-1998, and Addenda ANSI/IAS PRD 1a-1999, *Pressure Relief Devices for Natural Gas Vehicle (NGV) Fuel Containers*

[5] Sandia National Laboratories, *Technical Reference for Hydrogen Compatibility of Materials* at www.ca.sandia.gov/matlsTechRef/

ICS 43.060.40

Price based on 41 pages