

16 January 2019

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## **Agreement**

### **Concerning the Adoption of Harmonized Technical United Nations Regulations for Wheeled Vehicles, Equipment and Parts which can be Fitted and/or be Used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these United Nations Regulations\***

(Revision 3, including the amendments which entered into force on 14 September 2017)

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#### **Addendum 145 – UN Regulation No. 146**

Date of entry into force as an annex to the 1958 Agreement: 02 January 2019

#### **Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety-related performance of hydrogen-fuelled vehicles of categories L1, L2, L3, L4 and L5**

This document is meant purely as documentation tool. The authentic and legal binding text is: ECE/TRANS/WP.29/2018/68.



**UNITED NATIONS**

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\* Former titles of the Agreement:  
Agreement concerning the Adoption of Uniform Conditions of Approval and Reciprocal Recognition of Approval for Motor Vehicle Equipment and Parts, done at Geneva on 20 March 1958 (original version);  
Agreement concerning the Adoption of Uniform Technical Prescriptions for Wheeled Vehicles, Equipment and Parts which can be Fitted and/or be Used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these Prescriptions, done at Geneva on 5 October 1995 (Revision 2).



## UN Regulation No. 146

### Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety-related performance of hydrogen-fuelled vehicles of categories L<sub>1</sub>, L<sub>2</sub>, L<sub>3</sub>, L<sub>4</sub> and L<sub>5</sub>

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## 1. Scope

This Regulation does not cover post-crash safety requirements of road vehicles and applies to: <sup>1</sup>

- 1.1. Part I - Compressed hydrogen storage systems for hydrogen-fuelled vehicles of categories L<sub>1</sub>, L<sub>2</sub>, L<sub>3</sub>, L<sub>4</sub> and L<sub>5</sub><sup>2</sup> on their safety-related performance.
- 1.2. Part II - Specific components for compressed hydrogen storage systems for hydrogen-fuelled vehicles of categories L<sub>1</sub>, L<sub>2</sub>, L<sub>3</sub>, L<sub>4</sub> and L<sub>5</sub> on their safety-related performance.
- 1.3. Part III - Hydrogen-fuelled vehicles of categories L<sub>1</sub>, L<sub>2</sub>, L<sub>3</sub>, L<sub>4</sub> and L<sub>5</sub> incorporating compressed hydrogen storage system on its safety-related performance.

## 2. Definitions

For the purposes of this Regulation, the following definitions shall apply:

- 2.1. "*Burst disc*" means the non-reclosing operating part of a pressure relief device which, when installed in the device, is designed to burst at a predetermined pressure to permit the discharge of compressed hydrogen.
- 2.2. "*Check valve*" means a non-return valve that prevents reverse flow in the vehicle fuel line.
- 2.3. "*Compressed hydrogen storage system (CHSS)*" means a system designed to store hydrogen fuel for a hydrogen-fuelled vehicle and composed of a pressurized container, pressure relief devices (PRDs) and shut off device(s) that isolate the stored hydrogen from the remainder of the fuel system and its environment.
- 2.4. "*Container*" (for hydrogen storage) means the component within the hydrogen storage system that stores the primary volume of hydrogen fuel.
- 2.5. "*Date of removal from service*" means the date (month and year) specified for removal from service.
- 2.6. "*Date of manufacture*" (of a compressed hydrogen container) means the date (month and year) of the proof pressure test carried out during manufacture.
- 2.7. "*Enclosed or semi-enclosed spaces*" means the special volumes within the vehicle (or the vehicle outline across openings) that are external to the hydrogen system (storage system, fuel cell system and fuel flow management system) and its housings (if any) where hydrogen may accumulate (and thereby pose a hazard), as it may occur in the passenger compartment, luggage compartment and space under the hood.
- 2.8. "*Exhaust point of discharge*" means the geometric centre of the area where fuel cell purged gas is discharged from the vehicle.

<sup>1</sup> This Regulation does not cover the electrical safety of electric power train, the material compatibility and hydrogen embrittlement of the vehicle fuel system.

<sup>2</sup> As defined in the Consolidated Resolution on the Construction of Vehicles (R.E.3.), document ECE/TRANS/WP.29/78/Rev.6, para. 2. – [www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29resolutions.html](http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29resolutions.html)

- 2.9. "*Fuel cell system*" means a system containing the fuel cell stack(s), air processing system, fuel flow control system, exhaust system, thermal management system and water management system.
- 2.10. "*Fuelling receptacle*" means the equipment to which a fuelling station nozzle attaches to the vehicle and through which fuel is transferred to the vehicle. The fuelling receptacle is used as an alternative to a fuelling port.
- 2.11. "*Hydrogen concentration*" means the percentage of the hydrogen moles (or molecules) within the mixture of hydrogen and air (equivalent to the partial volume of hydrogen gas).
- 2.12. "*Hydrogen-fuelled vehicle*" means any motor vehicle that uses compressed gaseous hydrogen as a fuel to propel the vehicle, including fuel cell and internal combustion engine vehicles. Hydrogen fuel for passenger vehicles is specified in ISO 14687-2: 2012 and SAE J2719: (September 2011 Revision).
- 2.13. "*Luggage compartment*" means the space in the vehicle for luggage and/or goods accommodation, bounded by the roof, hood, floor, side walls, being separated from the passenger compartment by the front bulkhead or the rear bulkhead.
- 2.14. "*Manufacturer*" means the person or body responsible to the approval authority for all aspects of the type approval process and for ensuring conformity of production. It is not essential that the person or body is directly involved in all stages of the construction of the vehicle, system or component which is the subject of the approval process.
- 2.15. "*Maximum allowable working pressure (MAWP)*" means the highest gauge pressure to which a pressure container or storage system is permitted to operate under normal operating conditions.
- 2.16. "*Maximum fuelling pressure (MFP)*" means the maximum pressure applied to compressed system during fuelling. The maximum fuelling pressure is 125 per cent of the Nominal Working Pressure.
- 2.17. "*Nominal working pressure (NWP)*" means the gauge pressure that characterizes typical operation of a system. For compressed hydrogen gas containers, NWP is the settled pressure of compressed gas in fully fuelled container or storage system at a uniform temperature of 15 °C.
- 2.18. "*Pressure relief device (PRD)*" means a device that, when activated under specified performance conditions, is used to release hydrogen from a pressurized system and thereby prevent failure of the system.
- 2.19. "*Rupture*" or "*burst*" both mean to come apart suddenly and violently, break open or fly into pieces due to the force of internal pressure.
- 2.20. "*Safety relief valve*" means a pressure relief device that opens at a preset pressure level and can re-close.
- 2.21. "*Service life*" (of a compressed hydrogen container) means the time frame during which service (usage) is authorized.
- 2.22. "*Shut-off valve*" means a valve between the storage container and the vehicle fuel system that can be automatically activated; which defaults to the "closed" position when not connected to a power source.
- 2.23. "*Single failure*" means a failure caused by a single event, including any consequential failures resulting from this failure.

- 2.24. "*Thermally-activated pressure relief device (TPRD)*" means a non- reclosing PRD that is activated by temperature to open and release hydrogen gas.
- 2.25. "*Type of hydrogen storage system*" means an assembly of components which do not differ significantly in such essential aspects as:
- (a) The manufacturer's trade name or mark;
  - (b) The state of stored hydrogen fuel; compressed gas;
  - (c) The nominal working pressure (NWP);
  - (d) The structure, materials, capacity and physical dimensions of the container; and
  - (e) The structure, materials and essential characteristics of TPRD, check valve and shut-off valve, if any.
- 2.26. "*Type of specific components of hydrogen storage system*" means a component or an assembly of components which do not differ significantly in such essential aspects as:
- (a) The manufacturer's trade name or mark;
  - (b) The state of stored hydrogen fuel; compressed gas;
  - (c) The sort of component: (T) PRD, check-valve or shut-off valve; and
  - (d) The structure, materials and essential characteristics.
- 2.27. "*Vehicle type*" with regard to hydrogen safety means vehicles which do not differ in such essential aspects as:
- (a) The manufacturer's trade name or mark; and
  - (b) The basic configuration and main characteristics of the vehicle fuel system.
- 2.28. "*Vehicle fuel system*" means an assembly of components used to store or supply hydrogen fuel to a fuel cell (FC) or internal combustion engine (ICE).

### **3. Application for approval**

- 3.1. Part I: Application for approval of a type of the compressed hydrogen storage system.
- 3.1.1. The application for approval of a type of hydrogen storage system shall be submitted by the manufacturer of the hydrogen storage system or by their authorized representative.
- 3.1.2. A model of information document is shown in Annex 1, Part 1-I.
- 3.1.3. A sufficient number of hydrogen storage systems representatives of the type to be approved shall be submitted to the Technical Service conducting the approval tests.
- 3.2. Part II: Application for approval of a type of specific component for compressed hydrogen storage system.
- 3.2.1. The application for approval of a type of specific component shall be submitted by the manufacturer of the specific component or by their authorized representative.

- 3.2.2. A model of information document is shown in Annex 1, Part 1-II.
- 3.2.3. A sufficient number of specific components of hydrogen storage system representatives of the type to be approved shall be submitted to the Technical Service conducting the approval tests.
- 3.3. Part III: Application for approval of a vehicle type.
- 3.3.1. The application for approval of a vehicle type shall be submitted by the vehicle manufacturer or by their authorized representative.
- 3.3.2. A model of information document is shown in Annex 1, Part 1- III.
- 3.3.3. A sufficient number of vehicles representatives of the type to be approved shall be submitted to the Technical Service conducting the approval tests.

## **4. Approval**

- 4.1. Granting of type approval.
  - 4.1.1. Approval of a type of compressed hydrogen storage system.

If the hydrogen storage system submitted for approval pursuant to this Regulation meets the requirements of Part I below, approval of that type of hydrogen storage system shall be granted.
  - 4.1.2. Approval of a type of specific component for the compressed hydrogen storage system.

If the specific component submitted for approval pursuant to this Regulation meets the requirements of Part II below, approval of that type of specific component shall be granted.
  - 4.1.3. Approval of a vehicle type.

If the vehicle submitted for approval pursuant to this Regulation meets the requirements of Part III below, approval of that vehicle type shall be granted.
- 4.2. An approval number shall be assigned to each type approved: its first two digits (00 for the UN Regulation in its initial form) shall indicate the series of amendments incorporating the most recent major technical amendments made to the UN Regulation at the time of issue of the approval. The same Contracting Party shall not assign the same number to another vehicle or component type.
- 4.3. Notice of approval or of extension, refusal or withdrawal of approval pursuant to this Regulation shall be communicated to the Contracting Parties to the Agreement which apply this Regulation by means of a form conforming to the model in Annex 1, Part 2 and photographs and/or plans supplied by the applicant being in a format not exceeding A4 (210 x 297 mm), or folded to that format, and on an appropriate scale.
- 4.4. There shall be affixed, conspicuously and in a readily accessible place specified on the approval form, to every vehicle, hydrogen storage system or specific component conforming to a type approved under this Regulation, an international approval mark conforming to the models described in Annex 2, consisting of:



- 4.4.1. A circle surrounding the letter "E" followed by the distinguishing number of the country which has granted approval;<sup>3</sup>
- 4.4.2. The number of this Regulation, followed by the letter "R", a dash and the approval number to the right of the circle prescribed in paragraph 4.4.1.
- 4.5. If the vehicle conforms to a vehicle type approved under one or more other UN Regulations, annexed to the Agreement, in the country which has granted approval under this Regulation, the symbol prescribed in paragraph 4.4.1. needs not be repeated; in such a case, the UN Regulation and approval numbers and the additional symbols shall be placed in vertical columns to the right of the symbol prescribed in paragraph 4.4.1. above.
- 4.6. The approval mark shall be clearly legible and be indelible.
- 4.6.1. In the case of a vehicle, the approval mark shall be placed close to or on the vehicle data plate.
- 4.6.2. In the case of a hydrogen storage system, the approval mark shall be placed on the container.
- 4.6.3. In the case of a specific component, the approval mark shall be placed on the specific component.

## **5. Part I – Specifications of the compressed hydrogen storage system**

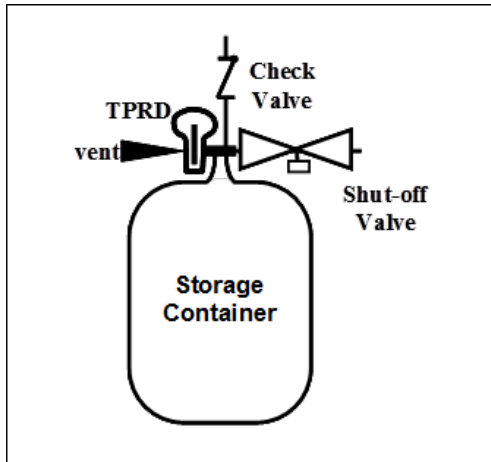
This part specifies the requirements for the compressed hydrogen storage system. The hydrogen storage system consists of the high pressure storage container and primary closure devices for openings into the high pressure storage container. Figure 1 shows a typical compressed hydrogen storage system consisting of a pressurized container, three closure devices and their fittings. The closure devices shall include the following functions, which may be combined:

- (a) TPRD;
- (b) Check valve that prevents reverse flow to the fill line; and
- (c) Automatic shut-off valve that can close to prevent flow from the container to the fuel cell or internal combustion engine. Any shut-off valve, and TPRD that form the primary closure of flow from the storage container shall be mounted directly on or within each container. At least one component with a check valve function shall be mounted directly on or within each container.

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<sup>3</sup> The distinguishing numbers of the Contracting Parties to the 1958 Agreement are reproduced in Annex 3 to the Consolidated Resolution on the Construction of Vehicles (R.E.3), document ECE/TRANS/WP.29/78/Rev.6, Annex 3 - [www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29resolutions.html](http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29resolutions.html)

Figure 1  
**Typical compressed hydrogen storage system**



A container shall be metal liner reinforced with a resin impregnated continuous filament (fully wrapped) and with a water capacity of 23 litres or less.

All new compressed hydrogen storage systems produced for on-road vehicle service shall have a NWP of 70 MPa or less, a service life of 15 years or less, and be capable of satisfying the requirements of paragraph 5.

The hydrogen storage system shall meet the performance test requirements specified in this paragraph. The qualification requirements for on-road service are:

- 5.1. Verification tests for baseline metrics
- 5.2. Verification test for performance durability (hydraulic sequential tests)
- 5.3. Verification test for expected on-road system performance (pneumatic sequential tests)
- 5.4. Verification test for service terminating system performance in Fire
- 5.5. Verification test for performance durability of primary closures.

The test elements within these performance requirements are summarized in Table 1. The corresponding test procedures are specified in Annex 3.

Table 1  
**Overview of performance requirements**

5.1.	Verification tests for baseline metrics
5.1.1.	Baseline initial burst pressure
5.1.2.	Baseline initial pressure cycle life
5.2.	Verification test for performance durability (Hydraulic sequential tests)
5.2.1.	Proof pressure test
5.2.2.	Drop (impact) test
5.2.3.	Surface damage test
5.2.4.	Chemical exposure and ambient-temperature pressure cycling tests
5.2.5.	High temperature static pressure test

5.2.6.	Extreme temperature pressure cycling
5.2.7.	Residual proof pressure test
5.2.8.	Residual strength burst test
5.3.	Verification test for expected on-road performance (Pneumatic sequential tests)
5.3.1.	Proof pressure test
5.3.2.	Ambient and extreme temperature gas pressure cycling test
5.3.3.	Extreme temperature static gas pressure leak/permeation test
5.3.4.	Residual proof pressure test (hydraulic)
5.3.5.	Residual strength burst test (hydraulic)
5.4.	Verification test for service terminating performance in fire
5.5.	Requirements for primary closure devices

5.1. Verification tests for baseline metrics

5.1.1. Baseline initial burst pressure

Three (3) containers shall be hydraulically pressurized until burst (Annex 3, paragraph 2.1. test procedure). The manufacturer shall supply documentation (measurements and statistical analyses) that establish the midpoint burst pressure of new storage containers, BPO.

All containers tested shall have a burst pressure within  $\pm 10$  per cent of BPO and greater than or equal to a minimum BP<sub>min</sub> of 225 per cent NWP.

In addition, containers having glass-fibre composite as a primary constituent to have a minimum burst pressure greater than 350 per cent NWP.

5.1.2. Baseline initial pressure cycle life

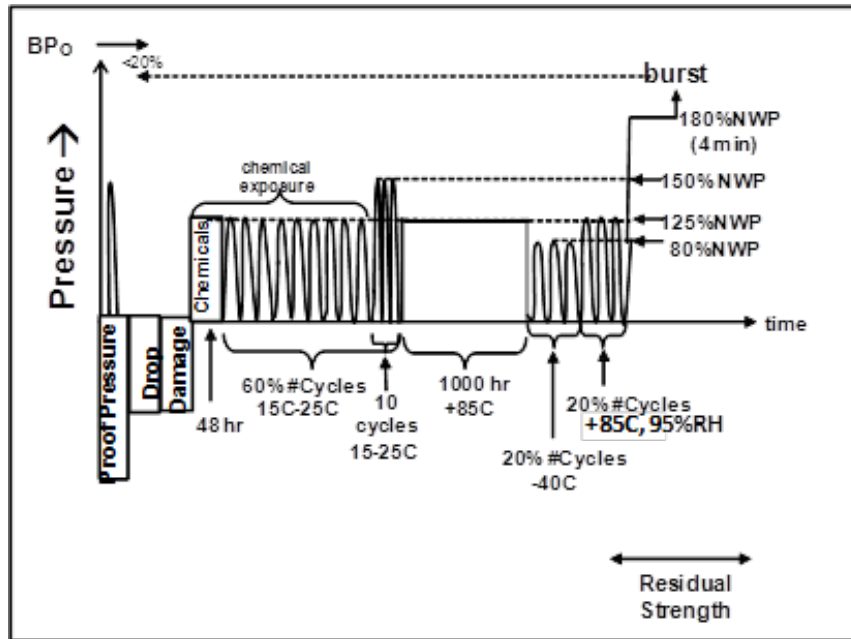
Three (3) containers shall be hydraulically pressure cycled at the ambient temperature of 20 ( $\pm 5$ ) °C to 125 per cent NWP (+2/-0 MPa) without rupture for 22,000 cycles or until a leak occurs (Annex 3, paragraph 2.2. test procedure). Leakage shall not occur within 11,000 cycles for a 15-year service life.

5.2. Verification tests for performance durability (Hydraulic sequential tests)

If all three pressure cycle life measurements made in paragraph 5.1.2. are greater than 11,000 cycles, or if they are all within  $\pm 25$  per cent of each other, then only one (1) container is tested in paragraph 5.2. Otherwise, three (3) containers are tested in paragraph 5.2.

A hydrogen storage container shall not leak during the following sequence of tests, which are applied in series to a single system and which are illustrated in Figure 2. Specifics of applicable test procedures for the hydrogen storage system are provided in Annex 3, paragraph 3.

Figure 2  
Verification test for performance durability (hydraulic)



5.2.1. Proof pressure test

A storage container is pressurized to 150 per cent NWP (+2/-0 MPa) and held for at least 30 sec (Annex 3, paragraph 3.1. test procedure).

5.2.2. Drop (impact) test

The storage container is dropped at several impact angles (Annex 3, paragraph 3.2. test procedure).

5.2.3. Surface damage test

The storage container is subjected to surface damage (Annex 3, paragraph 3.3. test procedure).

5.2.4. Chemical exposure and ambient-temperature pressure cycling test

The storage container is exposed to chemicals found in the on-road environment and pressure cycled to 125 per cent NWP (+2/-0 MPa) at 20 ( $\pm 5$ ) °C for 60 per cent number of Cycles pressure cycles (Annex 3, paragraph 3.4. test procedure). Chemical exposure is discontinued before the last 10 cycles, which are conducted to 150 per cent NWP (+2/-0 MPa).

5.2.5. High temperature static pressure test.

The storage container is pressurized to 125 per cent NWP (+2/-0 MPa) at  $\geq 85$  °C for at least 1,000 hours (Annex 3, paragraph 3.5. test procedure).

5.2.6. Extreme temperature pressure cycling.

The storage container is pressure cycled at  $\leq -40$  °C to 80 per cent NWP (+2/-0 MPa) for 20 per cent number of Cycles and at  $\geq +85$  °C and 95 ( $\pm 2$ ) per cent relative humidity to 125 per cent NWP (+2/-0 MPa) for 20 per cent number of Cycles (Annex 3, paragraph 2.2. test procedure).

## 5.2.7. Residual proof pressure test

The storage container is pressurized to 180 per cent NWP (+2/-0 MPa) and held at least 4 minutes without burst (Annex 3, paragraph 3.1. test procedure).

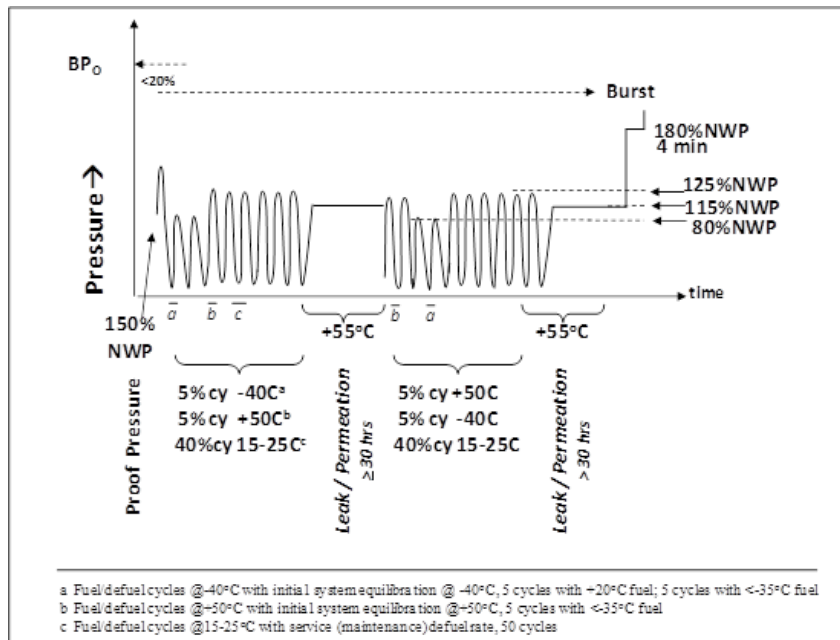
## 5.2.8. Residual strength burst test

The storage container undergoes a hydraulic burst test to verify that the burst pressure is at least 80 per cent of the baseline initial burst pressure (BPO) determined in paragraph 5.1.1. (Annex 3, paragraph 2.1. test procedure).

## 5.3. Verification test for expected on-road performance (Pneumatic sequential tests)

A hydrogen storage system shall not leak during the following sequence of tests, which are illustrated in Figure 3. Specifics of applicable test procedures for the hydrogen storage system are provided in Annex 3.

Figure 3

**Verification test for expected on-road performance (pneumatic/hydraulic)**

## 5.3.1. Proof pressure test

A system is pressurized to 150 per cent NWP (+2/-0 MPa) for at least 30 seconds (Annex 3, paragraph 3.1. test procedure). A storage container that has undergone a proof pressure test in manufacture may be exempted from this test.

## 5.3.2. Ambient and extreme temperature gas pressure cycling test

The system is pressure cycled using hydrogen gas for 500 cycles (Annex 3, paragraph 4.1. test procedure).

- (a) The pressure cycles are divided into two groups: Half of the cycles (250) are performed before exposure to static pressure (paragraph 5.3.3.) and the remaining half of the cycles (250) are performed after the initial exposure to static pressure (paragraph 5.3.3.) as illustrated in Figure 3;
- (b) The first group of pressure cycling, 25 cycles are performed to 80 per cent NWP (+2/-0 MPa) at  $\leq -40$  °C, then 25 cycles to 125 per cent NWP (+2/-0 MPa) at  $\geq +50$  °C and 95 ( $\pm 2$ ) per cent relative humidity, and the remaining 200 cycles to 125 per cent NWP (+2/-0 MPa) at  $20 (\pm 5)$  °C;  
  
The second group of pressure cycling, 25 cycles are performed to 125 per cent NWP (+2/-0 MPa) at  $\geq +50$  °C and 95 ( $\pm 2$ ) per cent relative humidity, then 25 cycles to 80 per cent NWP (+2/-0 MPa) at  $\leq -40$  °C, and the remaining 200 cycles to 125 per cent NWP (+2/-0 MPa) at  $20 (\pm 5)$  °C.
- (c) The hydrogen gas fuel temperature is  $\leq -40$  °C;
- (d) During the first group of 250 pressure cycles, five cycles are performed with fuel having a temperature of  $+20 (\pm 5)$  °C after temperature equilibration of the system at  $\leq -40$  °C; five cycles are performed with fuel having a temperature of  $\leq -40$  °C; and five cycles are performed with fuel having a temperature of  $\leq -40$  °C after temperature equilibration of the system at  $\geq +50$  °C and 95 per cent relative humidity;
- (e) Fifty pressure cycles are performed using a de-fuelling rate greater than or equal to the maintenance de-fuelling rate.

5.3.3. Extreme temperature static gas pressure leak/permeation test.

- (a) The test is performed after each group of 250 pneumatic pressure cycles in paragraph 5.3.2.;
- (b) The maximum allowable hydrogen discharge from the compressed hydrogen storage system is 46 ml/hr/l water capacity of the storage system. (Annex 3, paragraph 4.2. test procedure);
- (c) If the measured permeation rate is greater than 0.005 mg/sec (3.6 Nml/min), a localized leak test is performed to ensure no point of localized external leakage is greater than 0.005 mg/sec (3.6 Nml/min) (Annex 3, paragraph 4.3. test procedure).

5.3.4. Residual proof pressure test (hydraulic)

The storage container is pressurized to 180 per cent NWP (+2/-0 MPa) and held at least 4 minutes without burst (Annex 3, paragraph 3.1. test procedure).

5.3.5. Residual strength burst test (hydraulic)

The storage container undergoes a hydraulic burst to verify that the burst pressure is at least 80 per cent of the baseline initial burst pressure (BPO) determined in paragraph 5.1.1. (Annex 3, paragraph 2.1. test procedure).

5.4. Verification test for service terminating performance in fire

This section describes the fire test with compressed hydrogen as the test gas. Compressed air may be used as an alternative test gas.

A hydrogen storage system is pressurized to NWP and exposed to fire (Annex 3, paragraph 5.1. test procedure). A temperature-activated pressure relief device shall release the contained gases in a controlled manner without rupture.

5.5. Requirements for primary closure devices

The primary closure devices that isolate the high pressure hydrogen storage system, namely TPRD, check valve and shut-off valve, as described in Figure 1, shall be tested and type-approved in accordance with Part II of this Regulation and produced in conformity with the approved type.

Retesting of the storage system is not required if alternative closure devices are provided having comparable function, fittings, materials, strength and dimensions, and satisfy the condition above. However, a change in TPRD hardware, its position of installation or venting lines shall require a new fire test in accordance with paragraph 5.4.

5.6. Labelling

A label shall be permanently affixed on each container with at least the following information: name of the manufacturer, serial number, date of manufacture, MFP, NWP, type of fuel (e.g. "CHG" for gaseous hydrogen), and date of removal from service. Each container shall also be marked with the number of cycles used in the testing programme as per paragraph 5.1.2. Any label affixed to the container in compliance with this paragraph shall remain in place and be legible for the duration of the manufacturer's recommended service life for the container.

Date of removal from service shall not be more than 15 years after the date of manufacture.

## 6. Part II – Specifications of specific components for the compressed hydrogen storage system

6.1. TPRD requirements

TPRDs shall meet the following performance requirements:

- (a) Pressure cycling test (Annex 4, paragraph 1.1.);
- (b) Accelerated life test (Annex 4, paragraph 1.2.);
- (c) Temperature cycling test (Annex 4, paragraph 1.3.);
- (d) Salt corrosion resistance test (Annex 4, paragraph 1.4.);
- (e) Vehicle environment test (Annex 4, paragraph 1.5.);
- (f) Stress corrosion cracking test (Annex 4, paragraph 1.6.);
- (g) Drop and vibration test (Annex 4, paragraph 1.7.);
- (h) Leak test (Annex 4, paragraph 1.8.);
- (i) Bench top activation test (Annex 4, paragraph 1.9.);
- (j) Flow rate test (Annex 4, paragraph 1.10.).

- 6.2. Check valve and automatic shut-off valve requirements
- Check valves and automatic shut-off valves shall meet the following performance requirements:
- (a) Hydrostatic strength test (Annex 4, paragraph 2.1.);
  - (b) Leak test (Annex 4, paragraph 2.2.);
  - (c) Extreme temperature pressure cycling test (Annex 4, paragraph 2.3.);
  - (d) Salt corrosion resistance test (Annex 4, paragraph 2.4.);
  - (e) Vehicle environment test (Annex 4, paragraph 2.5.);
  - (f) Atmospheric exposure test (Annex 4, paragraph 2.6.);
  - (g) Electrical tests (Annex 4, paragraph 2.7.);
  - (h) Vibration test (Annex 4, paragraph 2.8.);
  - (i) Stress corrosion cracking test (Annex 4, paragraph 2.9.);
  - (j) Pre-cooled hydrogen exposure test (Annex 4, paragraph 2.10.).
- 6.3. At least the following information: MFP and type of fuel (e.g. "CHG" for gaseous hydrogen), shall be marked on each component having the function(s) of the primary closure devices in clearly legible and indelible manner.

## **7. Part III – Specifications of a vehicle fuel system incorporating the compressed hydrogen storage system**

This part specifies requirements for the vehicle fuel system, which includes the compressed hydrogen storage system, piping, joints, and components in which hydrogen is present. The hydrogen storage system included in the vehicle fuel system shall be tested and type-approved in accordance with Part I of this Regulation and produced in conformity with the approved type.

- 7.1. In-use fuel system requirements
- 7.1.1. Fuelling receptacle
- 7.1.1.1. A compressed hydrogen fuelling receptacle shall prevent reverse flow to the atmosphere. Test procedure is by visual inspection.
- 7.1.1.2. Fuelling receptacle label: A label shall be affixed close to the fuelling receptacle; for instance inside a refilling hatch, showing the following information: fuel type (e.g. "CHG" for gaseous hydrogen), MFP, NWP, date of removal from service of containers.
- 7.1.1.3. The fuelling receptacle shall be mounted on the vehicle to ensure positive locking of the fuelling nozzle. The receptacle shall be protected from tampering and the ingress of dirt and water (e.g. installed in a compartment which can be locked). Test procedure is by visual inspection.
- 7.1.1.4. The fuelling receptacle shall not be mounted within the external energy absorbing elements of the vehicle (e.g. bumper) and shall not be installed in the passenger compartment, luggage compartment and other places where hydrogen gas could accumulate and where ventilation is not sufficient. Test procedure is by visual inspection.



7.1.2. Over-pressure protection for the low pressure system

The hydrogen system downstream of a pressure regulator shall be protected against overpressure due to the possible failure of the pressure regulator. The set pressure of the overpressure protection device shall be lower than or equal to the maximum allowable working pressure for the appropriate section of the hydrogen system.

The system is visually inspected for compliance.

7.1.3. Hydrogen discharge systems

7.1.3.1. Pressure relief systems

- (a) Storage system TPRDs. The outlet of the vent line, if present, for hydrogen gas discharge from TPRD(s) of the storage system shall be protected by a cap;
- (b) Storage system TPRDs. The hydrogen gas discharge from TPRD(s) of the storage system shall not be directed:
  - (i) Into enclosed or semi-enclosed spaces;
  - (ii) Into or towards any wheel housing of the vehicle or any braking component that is subject to elevated temperatures during intended use;
  - (iii) Towards hydrogen gas containers;
  - (iv) In any direction other than perpendicularly outward from the bottom of the vehicle body.
- (c) Other pressure relief devices (such as a burst disc) may be used outside the hydrogen storage system. The hydrogen gas discharge from other pressure relief devices shall not be directed:
  - (i) Towards exposed electrical terminals, exposed electrical switches or other ignition sources;
  - (ii) Into or towards the vehicle passenger or luggage compartments or towards the driver or any passengers on the vehicle;
  - (iii) Into or towards any wheel housing of the vehicle or any braking component that is subject to elevated temperatures during intended use.
  - (iv) Towards hydrogen gas containers.

The system is visually inspected for compliance.

7.1.3.2. Vehicle exhaust system (Annex 5, paragraph 2. test procedure)

At the vehicle exhaust system's point of discharge, the hydrogen concentration level shall:

- (a) Not exceed 4 per cent average by volume during any moving three-second time interval during normal operation including start-up and shut-down;
- (b) And not exceed 8 per cent at any time (Annex 5, paragraph 2. test procedure).

- 7.1.4. Protection against flammable conditions: single failure conditions
- 7.1.4.1. Hydrogen leakage and/or permeation from the hydrogen storage system shall not directly vent into the passenger or luggage compartments or towards the driver or any passengers on the vehicle, or to any enclosed or semi-enclosed spaces within the vehicle that contains unprotected ignition sources.
- 7.1.4.2. Any single failure downstream of the main hydrogen shut-off valve shall not result in accumulations in levels of hydrogen concentration in the passenger compartment according to test procedure in Annex 5, paragraph 1.2.
- 7.1.4.3. If, during operation, a single failure results in a hydrogen concentration exceeding 3.0 per cent by volume in air in the enclosed or semi-enclosed spaces of the vehicle, then a warning shall be provided (paragraph 7.1.6.). If the hydrogen concentration exceeds 4.0 per cent by volume in the air in the enclosed or semi-enclosed spaces of the vehicle, the main shut-off valve shall be closed to isolate the storage system. (Annex 5, paragraph 1. test procedure).
- 7.1.5. Fuel system leakage
- The hydrogen fuelling line (e.g. piping, joint, etc.) downstream of the main shut-off valve(s) to the fuel cell system or the engine shall not leak. Compliance shall be verified at NWP (Annex 5, paragraph 3. test procedure).
- 7.1.6. Tell-tale signal warning to driver
- The warning shall be given by a visual signal or display text with the following properties:
- (a) Visible to the driver while in the driver's designated seating position (with the driver's seat belt fastened if such restraint system is installed);
  - (b) Yellow in colour if the detection system malfunctions (e.g. circuit disconnection, short-circuit, sensor fault). It shall be red in compliance with section paragraph 7.1.4.3;
  - (c) When illuminated, shall be visible to the driver under both daylight and night time driving conditions;
  - (d) Remains illuminated when 3.0 per cent concentration or detection system malfunction exists and the ignition locking system is in the "On" ("Run") position or the propulsion system is activated.
- 7.2. Installation of the hydrogen container on-board a vehicle
- The vehicle fuel system shall be subject to the relevant accelerations specified below. The accelerations shall be measured at the location where the hydrogen storage system is installed. The vehicle fuel system shall be mounted and fixed on the representative part of the vehicle. The mass used shall be representative for a fully equipped and filled container or container assembly.
- Accelerations for vehicles:
- (a) 43.5 g in the direction of travel (forward and rearward direction);
  - (b) 63 g horizontally perpendicular to the direction of travel (to left and right).

- 7.2.1. Container Displacement
- The storage container(s) shall remain attached to the vehicle at a minimum of one attachment point and shall stay within the installed location(s) after the accelerations test specified above.
- 7.2.2. Additional installation requirements
- The test procedure shall be by visual inspection.
- 7.2.2.1. The container and primary closure devices for openings into the high pressure storage container shall not come in direct contact with the road surface in the event of turnover, etc.
- 7.2.2.2. The container and primary closure devices for openings into the high pressure storage container shall not come in direct contact with other parts, etc. (except protective part(s)) in the event of collision or vehicle crush, etc.
- 7.2.2.3. The container shall not be exposed to direct sunlight.

## **8. Modification of type and extension of approval**

- 8.1. Every modification to an existing type of vehicle or hydrogen storage system or specific component for hydrogen storage system shall be notified to the Type Approval Authority which approved that type. The Authority shall then either:
- (a) Decide, in consultation with the manufacturer, that a new type-approval is to be granted; or
  - (b) Apply the procedure contained in paragraph 8.1.1. (Revision) and, if applicable, the procedure contained in paragraph 8.1.2. (Extension).
- 8.1.1. Revision
- When particulars recorded in the information documents of Annex 1 have changed and the Type Approval Authority considers that the modifications made are unlikely to have an appreciable adverse effect and that in any case the vehicle/hydrogen storage system/specific component still meets the requirements, the modification shall be designated a "revision".
- In such a case, the Type Approval Authority shall issue the revised pages of the information documents of Annex 1 as necessary, marking each revised page to show clearly the nature of the modification and the date of re-issue. A consolidated, updated version of the information documents of Annex 1, accompanied by a detailed description of the modification, shall be deemed to meet this requirement.
- 8.1.2. Extension
- The modification shall be designated an "extension" if, in addition to the change of the particulars recorded in the information folder,
- (a) Further inspections or tests are required; or
  - (b) Any information on the communication document (with the exception of its attachments) has changed; or
  - (c) Approval to a later series of amendments is requested after its entry into force.

- 8.2. Confirmation or refusal of approval, specifying the alterations, shall be communicated by the procedure specified in paragraph 4.3. above to the Contracting Parties to the Agreement which apply this Regulation. In addition, the index to the information documents and to the test reports, attached to the communication document of Annex 1, shall be amended accordingly to show the date of the most recent revision or extension.
- 8.3. The Type Approval Authority issuing the extension of approval shall assign a serial number to each communication form drawn up for such an extension.

## **9. Conformity of production**

The conformity procedure shall comply with those set out in the Agreement, Schedule 1 (E/ECE/TRANS/505/Rev.3), and with the following requirements:

- 9.1. A vehicle, hydrogen storage system or component approved pursuant to this Regulation shall be so manufactured as to conform to the type approved by meeting the respective requirements of paragraphs 5. to 7. above;
- 9.2. The Type Approval Authority which has granted approval may at any time verify the conformity of control methods applicable to each production unit. The normal frequency of such inspections shall be once every two years.
- 9.3. In case of compressed hydrogen storage system, the production control of the container shall satisfy the following additional requirements;
- 9.3.1. Every container shall be tested in accordance with paragraph 5.2.1. of this Regulation. The test pressure is  $\geq 150$  per cent of NWP.
- 9.3.2. Batch testing
- In any case, for each batch, which is not permitted to exceed 200 finished cylinders or liners (not including destructive test cylinders or liners), or one shift of successive production, whichever is greater, at least one container shall be subjected to the rupture test in paragraph 9.3.2.1. and furthermore at least one container shall be subjected to the pressure cycle test in paragraph 9.3.2.2.
- 9.3.2.1. Rupture test in batch testing
- The test shall be performed according to paragraph 2.1. (hydrostatic pressure rupture test) of Annex 3. The required rupture pressure shall be at least BP<sub>min</sub> and the average burst pressure recorded of the last ten tests shall be at or above BPO-10 per cent.
- 9.3.2.2. Ambient temperature pressure cycling test in batch testing
- The test shall be performed according to paragraph 2.2. (a) to (c) (hydrostatic pressure cycling test) of Annex 3, except that the temperature requirements for the fuelling fluid and the container skin, and the relative humidity requirement, do not apply. The cylinder shall be pressure cycled using hydrostatic pressures  $\geq 125$  per cent of NWP, to 22,000 cycles in case of no leakage or until leakage occurs. For the service life of 15 years, the cylinder shall not leak or rupture within the first 11,000 cycles.

9.3.2.3. Relaxation provisions

In the ambient temperature pressure cycling test in batch testing, finished cylinders shall be pressure cycled at a sampling frequency defined as follows:

9.3.2.3.1. One cylinder from each batch shall be pressure cycled with 11,000 cycles for the service life of 15 years.

9.3.2.3.2. On 10 sequential production batches of the same design, should none of the pressure cycled cylinders leak or rupture in less than 11,000 cycles x 1.5 for the service life of 15 years, then the pressure cycling test can be reduced to one cylinder from every 5 batches of production.

9.3.2.3.3. On 10 sequential production batches of the same design, should none of the pressure cycled cylinders leak or rupture in less than 11,000 cycles x 2.0 for the service life of 15 years, then the pressure cycling test can be reduced to one cylinder from every 10 batches of production.

9.3.2.3.4. Should more than 6 months have expired since the last batch of production, then the sampling frequency for the next batch of production shall be that specified in paragraph 9.3.2.3.2. or 9.3.2.3.3. above.

9.3.2.3.5. Should any cylinder tested at the sampling frequency in paragraph 9.3.2.3.2. or 9.3.2.3.3. above fail to meet the required number of pressure cycles, then it shall be necessary to repeat the pressure cycling test at the sampling frequency in paragraph 9.3.2.3.1 above for a minimum 10 production batches. The sampling frequency for testing thereafter shall be that specified in paragraph 9.3.2.3.2. or 9.3.2.3.3. above.

9.3.2.3.6. Should any cylinder tested at the sampling frequency in paragraph 9.3.2.3.1., 9.3.2.3.2. or 9.3.2.3.3. above fail to meet the minimum requirement regarding the number of pressure cycles (11,000 cycles), then the cause of failure shall be determined and corrected following the procedures in paragraph 9.3.2.3.7.

The pressure cycling test shall then be repeated on an additional three cylinders from that batch. Should any of the three additional cylinders fail to meet the minimum requirement regarding the number of pressure cycles (11,000 cycles), then all cylinders of this batch shall be rejected.

9.3.2.3.7. In the event of failure to meet test requirements retesting or reheat treatment and retesting shall be carried out as follows:

- (a) If there is evidence of a fault in carrying out a test, or an error of measurement, a further test shall be performed. If the result of this test is satisfactory, the first test shall be ignored;
- (b) If the test has been carried out in a satisfactory manner, the cause of test failure shall be identified.

All cylinders that fail to meet the requirements shall be rejected or repaired by an approved method. The non-rejected cylinders are then considered as a new batch.

In any case, the new batch shall be retested. All the relevant prototype or batch tests needed to prove the acceptability of the new batch shall be performed again. If any cylinder in a batch is proven unsatisfactory by one or more tests, all cylinders of this batch shall be rejected.

## **10. Penalties for non-conformity of production**

- 10.1. The approval granted in respect of a vehicle, system or component type pursuant to this Regulation may be withdrawn if the requirements laid down in paragraph 9. above are not complied with.
- 10.2. If a Contracting Party withdraws an approval it had previously granted, it shall forthwith so notify the other Contracting Parties applying this Regulation by sending them a communication form conforming to the model set out in Part 2 of Annex 1 to this Regulation.

## **11. Production definitively discontinued**

If the holder of the approval completely ceases to manufacture a type of vehicle, system or component approved in accordance with this Regulation, he shall so inform the authority which granted the approval, which in turn shall forthwith inform the other Contracting Parties to the Agreement applying this Regulation by means of a communication form conforming to the model set out in Part 2 of Annex 1 to this Regulation.

## **12. Names and addresses of Technical Services responsible for conducting approval tests and of the Type Approval Authorities**

The Contracting Parties to the Agreement applying this Regulation shall communicate to the United Nations secretariat the names and addresses of the Technical Services responsible for conducting approval tests and of the Type Approval Authorities which grant approval and to which forms certifying approval or extension or refusal or withdrawal of approval are to be sent.

## Annex 1 - Part 1

### Model - I

#### **Information document No. ... on the type approval of a hydrogen storage system with regard to the safety-related performance of hydrogen-fuelled vehicles of categories L<sub>1</sub>, L<sub>2</sub>, L<sub>3</sub>, L<sub>4</sub> and L<sub>5</sub>**

The following information, if applicable, shall include a list of contents. Any drawings shall be supplied in appropriate scale and in sufficient detail on size A4 or on a folder of A4 format. Photographs, if any, shall show sufficient details.

If the systems or components have electronic controls, information concerning their performance shall be supplied.

- 0. General
  - 0.1. Make (trade name of manufacturer): .....
  - 0.2. Type:.....
  - 0.2.1. Commercial name(s) (if available): .....
  - 0.5. Name and address of manufacturer: .....
  - 0.8. Name(s) and address(es) of assembly plant(s):.....
  - 0.9. Name and address of the manufacturer's representative (if any): .....
- 3. Power Plant
  - 3.9. Hydrogen storage system
    - 3.9.1. Hydrogen storage system designed to use liquid / compressed (gaseous) hydrogen <sup>1</sup>
      - 3.9.1.1. Description and drawing of the hydrogen storage system: .....
      - 3.9.1.2. Make(s): .....
      - 3.9.1.3. Type(s): .....
    - 3.9.2. Container(s)
      - 3.9.2.1. Make(s): .....
      - 3.9.2.2. Type(s): .....
      - 3.9.2.3. Maximum Allowable Working Pressure (MAWP):      MPa
      - 3.9.2.4. Nominal working pressure(s):      MPa
      - 3.9.2.5. Number of filling cycles: .....
      - 3.9.2.6. Capacity:      litres (water)

<sup>1</sup> Delete where not applicable (there are cases where nothing needs to be deleted when more than one entry is applicable).

- 3.9.2.7. Material: .....
- 3.9.2.8. Description and drawing:.....
- 3.9.3. Thermally-activated pressure relief device(s)
- 3.9.3.1. Make(s): .....
- 3.9.3.2. Type(s): .....
- 3.9.3.3. Maximum Allowable Working Pressure (MAWP):     MPa
- 3.9.3.4. Set pressure:.....
- 3.9.3.5. Set temperature: .....
- 3.9.3.6. Blow off capacity: .....
- 3.9.3.7. Normal maximum operating temperature:     °C
- 3.9.3.8. Nominal working pressure(s):     MPa
- 3.9.3.9. Material: .....
- 3.9.3.10. Description and drawing:.....
- 3.9.3.11. Approval number:.....
- 3.9.4. Check valve(s)
- 3.9.4.1. Make(s): .....
- 3.9.4.2. Type(s): .....
- 3.9.4.3. Maximum Allowable Working Pressure (MAWP):     MPa
- 3.9.4.4. Nominal working pressure(s):     MPa
- 3.9.4.5. Material: .....
- 3.9.4.6. Description and drawing:.....
- 3.9.4.7. Approval number:.....
- 3.9.5. Automatic shut-off valve(s)
- 3.9.5.1. Make(s): .....
- 3.9.5.2. Type(s):.....
- 3.9.5.3. Maximum Allowable Working Pressure (MAWP):     MPa
- 3.9.5.4. Nominal working pressure(s) and if downstream of the first pressure regulator,  
maximum allowable working pressure(s):     MPa
- 3.9.5.5. Material: .....
- 3.9.5.6. Description and drawing:.....
- 3.9.5.7. Approval number:.....



## Annex 1 - Part 1

### Model - II

#### **Information document No. ... on the type approval of specific component for a hydrogen storage system with regard to the safety-related performance of hydrogen-fuelled vehicles of categories L<sub>1</sub>, L<sub>2</sub>, L<sub>3</sub>, L<sub>4</sub> and L<sub>5</sub>**

The following information, if applicable, shall include a list of contents. Any drawings shall be supplied in appropriate scale and in sufficient detail on size A4 or on a folder of A4 format. Photographs, if any, shall show sufficient details.

If the components have electronic controls, information concerning their performance shall be supplied.

- 0. General
  - 0.1. Make (trade name of manufacturer): .....
  - 0.2. Type:.....
  - 0.2.1. Commercial name(s) (if available): .....
  - 0.5. Name and address of manufacturer: .....
  - 0.8. Name(s) and address(es) of assembly plant(s):.....
  - 0.9. Name and address of the manufacturer's representative (if any): .....
- 3. Power Plant
  - 3.9.3. Thermally-activated pressure relief device(s)
    - 3.9.3.1. Make(s): .....
    - 3.9.3.2. Type(s): .....
    - 3.9.3.3. Maximum Allowable Working Pressure (MAWP):     MPa
    - 3.9.3.4. Set pressure:.....
    - 3.9.3.5. Set temperature: .....
    - 3.9.3.6. Blow off capacity: .....
    - 3.9.3.7. Normal maximum operating temperature:    °C
    - 3.9.3.8. Nominal working pressure(s):     MPa
    - 3.9.3.9. Material: .....
    - 3.9.3.10. Description and drawing:.....
  - 3.9.4. Check valve(s)
    - 3.9.4.1. Make(s): .....
    - 3.9.4.2. Type(s): .....
    - 3.9.4.3. Maximum Allowable Working Pressure (MAWP):     MPa

- 3.9.4.4. Nominal working pressure(s): MPa
- 3.9.4.5. Material: .....
- 3.9.4.6. Description and drawing:.....
- 3.9.5. Automatic shut-off valve(s)
- 3.9.5.1. Make(s): .....
- 3.9.5.2. Type(s):.....
- 3.9.5.3. Maximum Allowable Working Pressure (MAWP): MPa
- 3.9.5.4. Nominal working pressure(s) and if downstream of the first pressure regulator,  
maximum allowable working pressure(s): MPa:
- 3.9.5.5. Material: .....
- 3.9.5.6. Description and drawing:.....

## Annex 1 - Part 1

### Model - III

#### **Information document No. ... on the type approval of a vehicle with regard to the safety-related performance of hydrogen-fuelled vehicles of categories L<sub>1</sub>, L<sub>2</sub>, L<sub>3</sub>, L<sub>4</sub> and L<sub>5</sub>**

The following information, if applicable, shall include a list of contents. Any drawings shall be supplied in appropriate scale and in sufficient detail on size A4 or on a folder of A4 format. Photographs, if any, shall show sufficient details.

If the systems or components have electronic controls, information concerning their performance shall be supplied.

- 0. General
  - 0.1. Make (trade name of manufacturer): .....
  - 0.2. Type:
    - 0.2.1. Commercial name(s) (if available):
  - 0.3. Means of identification of type, if marked on the vehicle: <sup>2</sup>.....
  - 0.3.1. Location of that marking: .....
  - 0.4. Category of vehicle: <sup>3</sup> .....
  - 0.5. Name and address of manufacturer: .....
  - 0.8. Name(s) and address(es) of assembly plant(s):.....
  - 0.9. Name and address of the manufacturer's representative (if any): .....
- 1. General construction characteristics of the vehicle
  - 1.1. Photographs and/or drawings of a representative vehicle:.....
  - 1.3.3. Powered axles (number, position, interconnection): .....
  - 1.4. Chassis (if any) (overall drawing): .....
- 3. Power Plant
  - 3.9. Hydrogen storage system
    - 3.9.1. Hydrogen storage system designed to use liquid / compressed (gaseous) hydrogen <sup>4</sup>

<sup>2</sup> If means of identification of type contains characters not relevant to describe the vehicle type covered by this information document, such characters shall be represented in the documentation by the symbol "[.]" (e.g. [...]).

<sup>3</sup> As defined in the Consolidated Resolution on the Construction of Vehicles (R.E.3.), document ECE/TRANS/WP.29/78/Rev.6, para. 2 - [www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29resolutions.html](http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29resolutions.html)

<sup>4</sup> Delete where not applicable (there are cases where nothing needs to be deleted when more than one entry is applicable).

- 3.9.1.1. Description and drawing of the hydrogen storage system: .....
- 3.9.1.2. Make(s): .....
- 3.9.1.3. Type(s): .....
- 3.9.1.4. Approval Number: .....
  
- 3.9.6. Hydrogen leakage detection sensors: .....
- 3.9.6.1. Make(s): .....
- 3.9.6.2. Type(s): .....
  
- 3.9.7. Refuelling connection or receptacle
- 3.9.7.1. Make(s): .....
- 3.9.7.2. Type(s): .....
  
- 3.9.8. Drawings showing requirements for installation and operation.

## Annex 1 - Part 2

### Model I

### Communication

(Maximum format: A4 (210 x 297 mm))



issued by: Name of administration:

.....  
.....  
.....

Concerning:<sup>2</sup> Approval granted  
Approval extended  
Approval refused  
Approval withdrawn  
Production definitively discontinued

of a type of compressed hydrogen storage system with regard to the safety-related performance of hydrogen-fuelled vehicles pursuant to UN Regulation No. 146

Approval No.: ..... Extension No.: .....

1. Trademark: .....
2. Type and trade names: .....
3. Name and address of manufacturer:.....
4. If applicable, name and address of manufacturer's representative: .....
5. Brief description of hydrogen storage system:.....
6. Date of submission of hydrogen storage system for approval: .....
7. Technical Service performing the approval tests: .....
8. Date of report issued by that Service: .....
9. Number of report issued by that Service:.....
10. Approval with regard to the safety-related performance of hydrogen-fuelled vehicles is granted/refused:<sup>2</sup>.....
11. Place:.....
12. Date:.....
13. Signature: .....

<sup>1</sup> Distinguishing number of the country which has granted/extended/refused/withdrawn an approval (see approval provisions in the Regulation).

<sup>2</sup> Delete what does not apply.

- 14. The information document annexed to this communication: .....
- 15. Any remarks:.....

## Annex 1 - Part 2

### Model II

#### Communication

(Maximum format: A4 (210 x 297 mm))



issued by:                      Name of administration:

.....  
.....  
.....

- Concerning: <sup>42</sup> Approval granted  
                  Approval extended  
                  Approval refused  
                  Approval withdrawn  
                  Production definitively discontinued

of a type of specific component (TPRD / Check valve / Automatic shut-off valve<sup>2</sup>) with regard to the safety-related performance of hydrogen-fuelled vehicles pursuant to UN Regulation No. 146

Approval No.: .....

Extension No.: .....

1. Trademark: .....
2. Type and trade names: .....
3. Name and address of manufacturer: .....
4. If applicable, name and address of manufacturer's representative: .....
5. Brief description of specific component: .....
6. Date of submission of specific component for approval: .....
7. Technical Service performing the approval tests: .....
8. Date of report issued by that Service: .....
9. Number of report issued by that Service: .....
10. Approval with regard to the safety-related performance of hydrogen-fuelled vehicles is granted/refused: <sup>2</sup>.....
11. Place: .....
12. Date: .....
13. Signature: .....

<sup>1</sup> Distinguishing number of the country which has granted/extended/refused/withdrawn an approval (see approval provisions in the Regulation).

<sup>2</sup> Delete what does not apply.

- 14. The information document annexed to this communication: .....
- 15. Any remarks:.....



## Annex 1 - Part 2

### Model III

#### Communication

(Maximum format: A4 (210 x 297 mm))



issued by: Name of administration:

.....  
.....  
.....

- Concerning: <sup>62</sup> Approval granted  
Approval extended  
Approval refused  
Approval withdrawn  
Production definitively discontinued

of a type of vehicle with regard to the safety-related performance of hydrogen-fuelled vehicles pursuant to UN Regulation No. 146

Approval No.: .....

Extension No.: .....

1. Trademark: .....
2. Type and trade names: .....
3. Name and address of manufacturer:.....
4. If applicable, name and address of manufacturer's representative: .....
5. Brief description of vehicle:.....
6. Date of submission of vehicle for approval: .....
7. Technical Service performing the approval tests: .....
8. Date of report issued by that Service: .....
9. Number of report issued by that Service:.....
10. Approval with regard to the safety-related performance of hydrogen-fuelled vehicles is granted/refused: <sup>2</sup>.....

---

<sup>1</sup> Distinguishing number of the country which has granted/extended/refused/withdrawn an approval (see approval provisions in the Regulation).

<sup>2</sup> Delete what does not apply.

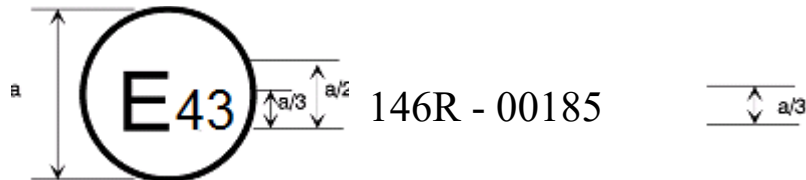
11. Place:.....
12. Date:.....
13. Signature: .....
14. The information document annexed to this communication: .....
15. Any remarks:.....

## Annex 2

### Arrangements of the approval marks

#### Model A

(See paragraphs 4.4. to 4.4.2. of this Regulation)

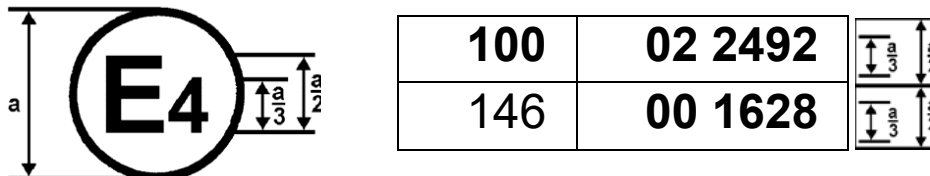


a = 8 mm min

The above approval mark affixed to a vehicle/ storage system/specific component shows that the vehicle/storage system/specific component type concerned has been approved in Japan (E 43) for its the safety-related performance of hydrogen-fuelled vehicles pursuant to UN Regulation No. 146. The first two digits of the approval number indicate that the approval was granted in accordance with the requirements of UN Regulation No. 146 in its original form.

#### Model B

(See paragraph 4.5. of this Regulation)



a = 8 mm min.

The above approval mark affixed to a vehicle shows that the road vehicle concerned has been approved in the Netherlands (E 4) pursuant to UN Regulations Nos. 146 and 100.\* The approval number indicates that, at the dates when the respective approvals were granted, UN Regulation No. 100 was amended by the 02 series of amendments and UN Regulation No. 146 was still in its original form.

\* The latter number is given only as an example.

## Annex 3

### Test procedures for the compressed hydrogen storage system

1. Test procedures for qualification requirements of compressed hydrogen storage are organized as follows:
  - Paragraph 2 of this annex is the test procedures for baseline performance metrics (requirement of paragraph 5.1. of this Regulation)
  - Paragraph 3 of this annex is the test procedures for performance durability (requirement of paragraph 5.2. of this Regulation)
  - Paragraph 4 of this annex is the test procedures for expected on-road performance (requirement of paragraph 5.3. of this Regulation)
  - Paragraph 5 of this annex is the test procedures for service terminating performance in fire (requirement of paragraph 5.4. of this Regulation)
  - Paragraph 6 of this annex is the test procedures for performance durability of primary closures (requirement of paragraph 5.5. of this Regulation)
2. Test procedures for baseline performance metrics (requirement of paragraph 5.1. of this Regulation)
  - 2.1. Burst test (hydraulic)

The burst test is conducted at the ambient temperature of 20 ( $\pm 5$ ) °C using a non-corrosive fluid. The rate of pressurization is less than or equal to 1.4 MPa/sec for pressures higher than 150 per cent of the nominal working pressure. If the rate exceeds 0.35 MPa/sec at pressures higher than 150 per cent NWP, then either the container is placed in series between the pressure source and the pressure measurement device, or the time at the pressure above a target burst pressure exceeds 5 seconds. The burst pressure of the container shall be recorded.
  - 2.2. Pressure cycling test (hydraulic)

The test is performed in accordance with the following procedure:

    - (a) The container is filled with a non-corrosive fluid;
    - (b) The container and fluid are stabilized at the specified temperature and relative humidity at the start of testing; the environment, fuelling fluid and container skin are maintained at the specified temperature for the duration of the testing. The container temperature may vary from the environmental temperature during testing;
    - (c) The container is pressure cycled between 2 ( $\pm 1$ ) MPa and the target pressure at a rate not exceeding 10 cycles per minute for the specified number of cycles;
    - (d) The temperature of the hydraulic fluid within the container is maintained and monitored at the specified temperature.
3. Test procedures for performance durability (requirement of paragraph 5.2. of this Regulation)
  - 3.1. Proof pressure test

The system is pressurized smoothly and continually with a non-corrosive hydraulic fluid until the target test pressure level is reached and then held for the specified time.

3.2. Drop (impact) test (unpressurized)

The storage container is drop tested at ambient temperature without internal pressurization or attached valves. The surface onto which the containers are dropped shall be a smooth, horizontal concrete pad or other flooring type with equivalent hardness.

The orientation of the container being dropped (in accordance with the requirement of paragraph 5.2.2.) is determined as follows: One or more additional container(s) shall be dropped in each of the orientations described below. The drop orientations may be executed with a single container or as many as four containers may be used to accomplish the four drop orientations.

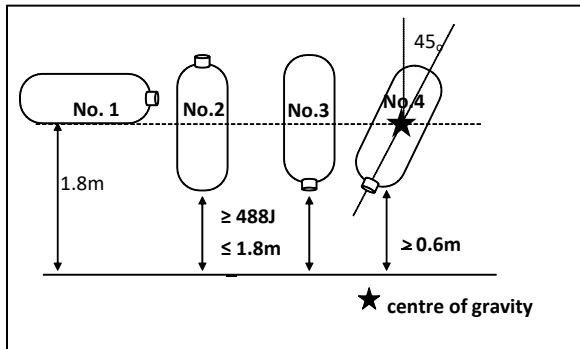
- (a) Dropped once from a horizontal position with the bottom 1.8 m above the surface onto which it is dropped;
- (b) Dropped once onto the end of the container from a vertical position with the ported end upward with a potential energy of not less than 488 J, with the height of the lower end no greater than 1.8 m. When the potential energy is not 488 J or over even if the height of the lower end is set to 1.8 m, drop the container with the height of the lower end at 1.8 m;\*
- (c) Dropped once onto the end of the container from a vertical position with the ported end downward with a potential energy of not less than 488 J, with the height of the lower end no greater than 1.8 m. When the potential energy is not 488 J or over even if the height of the lower end is set to 1.8 m, drop the container with the height of the lower end at 1.8 m. If the container is symmetrical (identical ported ends), this drop orientation is not required;
- (d) Dropped once at a 45° angle from the vertical orientation with a ported end downward with its centre of gravity 1.8 m above the ground. However, if the bottom is closer to the ground than 0.6 m, the drop angle shall be changed to maintain a minimum height of 0.6 m and a centre of gravity of 1.8 m above the ground.

The four drop orientations are illustrated in Figure 1.

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\* Note by the secretariat: the text of this subparagraph should be simplified.

Figure 1  
Drop orientations



No attempt shall be made to prevent the bouncing of containers, but the containers may be prevented from falling over during the vertical drop tests described above.

If more than one container is used to execute all drop specifications, then those containers shall undergo pressure cycling according to Annex 3, paragraph 2.2. until either leakage or 22,000 cycles without leakage have occurred. Leakage shall not occur within 11,000 cycles.

The orientation of the container being dropped in accordance with the requirement of paragraph 5.2.2. shall be identified as follows:

- (a) If a single container was subjected to all four drop orientations, then the container being dropped in accordance with the requirement of paragraph 5.2.2. shall be dropped in all four orientations;
- (b) If more than one container is used to execute the four drop orientations, and if all containers reach 22,000 cycles without leakage, then the orientation of the container being dropped in accordance with the requirement paragraph 5.2.2. is the  $45^\circ$  orientation (iv), and that container shall then undergo further testing as specified in paragraph 5.2.;
- (c) If more than one container is used to execute the four drop orientations and if any container does not reach 22,000 cycles without leakage, then the new container shall be subjected to the drop orientation(s) that resulted in the lowest number of cycles to leakage and then will undergo further testing as specified in paragraph 5.2.

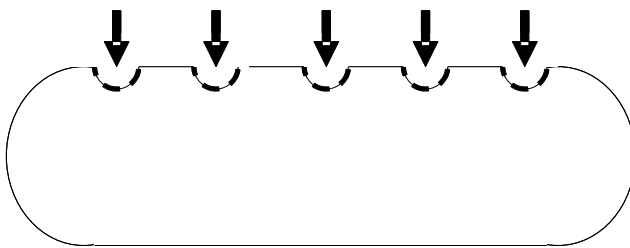
3.3. Surface damage test (unpressurized)

The test proceeds in the following sequence:

- (a) Surface flaw generation: Two longitudinal saw cuts are made on the bottom outer surface of the unpressurized horizontal storage container along the cylindrical zone close to but not in the shoulder area. The first cut is at least 1.25 mm deep and 25 mm long toward the valve end of the container. The second cut is at least 0.75 mm deep and 200 mm long toward the end of the container opposite the valve;
- (b) Pendulum impacts: The upper section of the horizontal storage container is divided into five distinct (not overlapping) areas 100 mm in diameter each (see Figure 2). After 12 hours preconditioning at

$\leq -40$  °C in an environmental chamber, the centre of each of the five areas sustains the impact of a pendulum having a pyramid with equilateral faces and square base, the summit and edges being rounded to a radius of 3 mm. The centre of impact of the pendulum coincides with the centre of gravity of the pyramid. The energy of the pendulum at the moment of impact with each of the five marked areas on the container is 30 J. The container is secured in place during pendulum impacts and not under pressure.

Figure 2  
Side view of container



**"Side" View of Container**

- 3.4. Chemical exposure and ambient-temperature pressure cycling test
- Each of the 5 areas of the unpressurized container preconditioned by pendulum impact (Annex 3, paragraph 3.3.) is exposed to one of five solutions:
- (a) 19 per cent (by volume) sulphuric acid in water (battery acid);
  - (b) 25 per cent (by weight) sodium hydroxide in water;
  - (c) 5 per cent (by volume) methanol in gasoline (fluids in fuelling stations);
  - (d) 28 per cent (by weight) ammonium nitrate in water (urea solution); and
  - (e) 50 per cent (by volume) methyl alcohol in water (windshield washer fluid).

The test container is oriented with the fluid exposure areas on top. A pad of glass wool approximately 0.5 mm thick and 100 mm in diameter is placed on each of the five preconditioned areas. A sufficient amount of the test fluid is applied to the glass wool sufficient to ensure that the pad is wetted across its surface and through its thickness for the duration of the test.

The exposure of the container with the glass wool is maintained for 48 hours with the container held at 125 per cent NWP (+2/-0 MPa) (applied hydraulically) and 20 ( $\pm 5$ ) °C before the container is subjected to further testing.

Pressure cycling is performed to the specified target pressures according to paragraph 2.2. of this Annex at 20 ( $\pm 5$ ) °C for the specified numbers of cycles. The glass wool pads are removed and the container surface is rinsed with water the final 10 cycles to specified final target pressure are conducted.

- 3.5. Static pressure test (hydraulic)

The storage system is pressurized to the target pressure in a temperature-controlled chamber. The temperature of the chamber and the non-corrosive fuelling fluid is held at the target temperature within  $\pm 5$  °C for the specified duration.

4. Test procedures for expected on-road performance (paragraph 5.3. of this Regulation)

(Pneumatic test procedures are provided; hydraulic test elements are described in Annex 3, paragraph 2.1.)

- 4.1. Gas pressure cycling test (pneumatic)

At the onset of testing, the storage system is stabilized at the specified temperature, relative humidity and fuel level for at least 24 hours. The specified temperature and relative humidity is maintained within the test environment throughout the remainder of the test. (When required in the test specification, the system temperature is stabilized at the external environmental temperature between pressure cycles.) The storage system is pressure cycled between less than 2 (+0/-1) MPa and the specified maximum pressure ( $\pm 1$  MPa). If system controls that are active in vehicle service prevent the pressure from dropping below a specified pressure, the test cycles shall not go below that specified pressure. The fill rate is controlled to a constant 3-minute pressure ramp rate, but with the fuel flow not to exceed 60 g/sec; the temperature of the hydrogen fuel dispensed to the container is controlled to the specified temperature. However, the pressure ramp rate should be decreased if the gas temperature in the container exceeds +85 °C. The defuelling rate is controlled to greater than or equal to the intended vehicle's maximum fuel-demand rate. The specified number of pressure cycles is conducted. If devices and/or controls are used in the intended vehicle application to prevent an extreme internal temperature, the test may be conducted with these devices and/or controls (or equivalent measures).

- 4.2. Gas permeation test (pneumatic)

A storage system is fully filled with hydrogen gas at 115 per cent NWP (+2/-0 MPa) (full fill density equivalent to 100 per cent NWP at +15 °C is 113 per cent NWP at +55 °C) and held at  $\geq +55$  °C in a sealed container until steady-state permeation or 30 hours, whichever is longer. The total steady-state discharge rate due to leakage and permeation from the storage system is measured.

- 4.3. Localized gas leak test (pneumatic)

A bubble test may be used to fulfil this requirement. The following procedure is used when conducting the bubble test:

- (a) The exhaust of the shut-off valve (and other internal connections to hydrogen systems) shall be capped for this test (as the test is focused on external leakage).

At the discretion of the tester, the test article may be immersed in the leak-test fluid or leak-test fluid applied to the test article when resting in open air. Bubbles can vary greatly in size, depending on conditions. The tester estimates the gas leakage based on the size and rate of bubble formation.

- (b) *Note:* For a localized rate of 0.005 mg/sec (3.6 Nml/min), the resultant allowable rate of bubble generation is about 2,030 bubbles per minute



for a typical bubble size of 1.5 mm in diameter. Even if much larger bubbles are formed, the leak should be readily detectable. For an unusually large bubble size of 6 mm in diameter, the allowable bubble rate would be approximately 32 bubbles per minute.

5. Test procedures for service terminating performance in fire (paragraph 5.4. of this Regulation)

5.1. Fire test

The hydrogen container assembly consists of the compressed hydrogen storage system with additional relevant features, including the venting system (such as the vent line and vent line covering) and any shielding affixed directly to the container (such as thermal wraps of the container(s) and/or coverings/barriers over the TPRD(s)).

Either one of the following two methods are used to identify the position of the system over the initial (localized) fire source:

- (a) Method 1: Qualification for a generic (non-Specific) vehicle installation

If a vehicle installation configuration is not specified (and the type approval of the system is not limited to a specific vehicle installation configuration) then the localized fire exposure area is the area on the test article farthest from the TPRD(s). The test article, as specified above, only includes thermal shielding or other mitigation devices affixed directly to the container that are used in all vehicle applications. Venting system(s) (such as the vent line and vent line covering) and/or coverings/barriers over the TPRD(s) are included in the container assembly if they are anticipated for use in any application. If a system is tested without representative components, retesting of that system is required if a vehicle application specifies the use of these type of components.

- (b) Method 2: Qualification for a specific vehicle installation

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

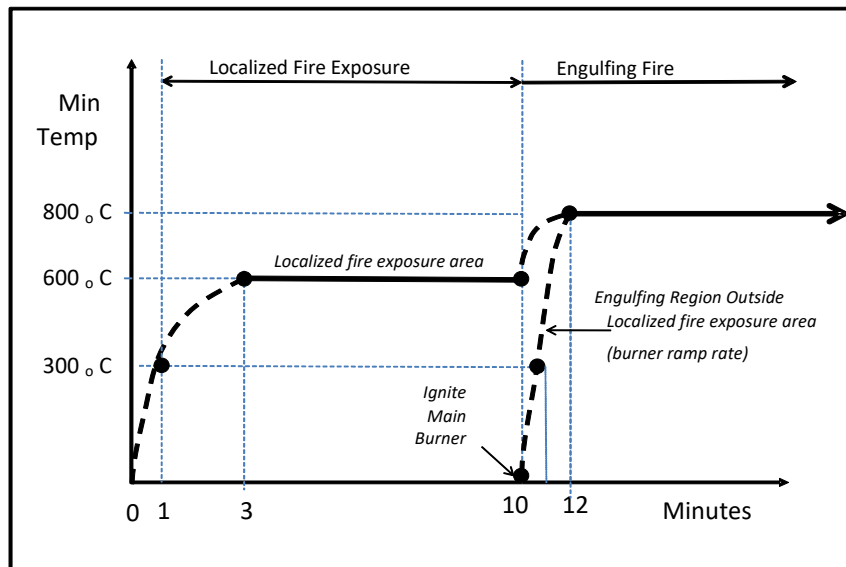
- 5.1.1. The container may be subjected to engulfing fire without any shielding components, as described in Annex 3, paragraph 5.2.

- 5.1.2. The following test requirements apply whether Method 1 or 2 (above) is used:

- (a) The container assembly is filled with compressed hydrogen gas at 100 per cent of NWP (+2/-0 MPa). The container assembly is positioned horizontally approximately 100 mm above the fire source;
- (b) Localized portion of the fire test:

- (i) The localized fire exposure area is located on the test article furthest from the TPRD(s). If Method 2 is selected and more vulnerable areas are identified for a specific vehicle installation configuration, the more vulnerable area that is furthest from the TPRD(s) is positioned directly over the initial fire source;
- (ii) The fire source consists of LPG burners configured to produce a uniform minimum temperature on the test article measured with a minimum 5 thermocouples covering the length of the test article up to 1.65 m maximum (at least 2 thermocouples within the localized fire exposure area, and at least 3 thermocouples equally spaced and no more than 0.5 m apart in the remaining area) located 25 ( $\pm 10$ ) mm from the outside surface of the test article along its longitudinal axis. At the option of the manufacturer or testing facility, additional thermocouples may be located at TPRD sensing points or any other locations for optional diagnostic purposes;
- (iii) Wind shields are applied to ensure uniform heating;
- (iv) The fire source initiates within a 250 ( $\pm 50$ ) mm longitudinal expanse positioned under the localized fire exposure area of the test article. The width of the fire source encompasses the entire diameter (width) of the storage system. If Method 2 is selected, the length and width shall be reduced, if necessary, to account for vehicle-specific features;
- (v) As shown in Figure 3 the temperature of the thermocouples in the localized fire exposure area has increased continuously to at least 300 °C within 1 minute of ignition, to at least 600 °C within 3 minutes of ignition, and a temperature of at least 600 °C is maintained for the next 7 minutes. The temperature in the localized fire exposure area shall not exceed 900 °C during this period. Compliance to the thermal requirements begins 1 minute after entering the period with minimum and maximum limits and is based on a 1-minute rolling average of each thermocouple in the region of interest. (*Note:* The temperature outside the region of the initial fire source is not specified during these initial 10 minutes from the time of ignition.).

Figure 3  
Temperature profile of fire test



(c) Engulfing portion of the fire test

Within the next 2-minute interval, the temperature along the entire surface of the test article shall be increased to at least 800 °C and the fire source is extended to produce a uniform temperature along the entire length up to 1.65 m and the entire width of the test article (engulfing fire). The minimum temperature is held at 800 °C, and the maximum temperature shall not exceed 1,100 °C. Compliance to thermal requirements begins 1 minute after entering the period with constant minimum and maximum limits and is based on a 1-minute rolling average of each thermocouple.

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

Table 1  
Summary of fire test protocol

	<i>Localized Fire Region</i>	<i>Time Period</i>	<i>Engulfing Fire Region (Outside the Localized Fire Region)</i>
Action	Ignite Burners	0-1 Minute	No Burner Operation
Minimum temperature	Not specified		Not specified
Maximum temperature	Less than 900 °C		Not specified
Action	Increase temperature and stabilize fire for start of localized fire exposure	1-3 Minutes	No Burner Operation
Minimum temperature	Greater than 300 °C		Not specified
Maximum temperature	Less than 900 °C		Not specified
Action	Localized fire exposure continues		No Burner Operation
Minimum temperature	1-minute rolling average greater than 600 °C		Not specified
Maximum temperature	1-minute rolling average less than 900 °C	3-10 Minutes	Not specified
Action	Increase temperature		Main Burner Ignited at 10 minutes
Minimum Temperature	1-minute rolling average greater than 600 °C		Not specified
Maximum temperature	1-minute rolling average less than 1,100 °C	10-11 Minutes	Less than 1,100 °C
Action	Increase temperature and stabilize fire for start of engulfing fire exposure		Increase temperature and stabilize fire for start of engulfing fire exposure
Minimum temperature	1-minute rolling average greater than 600 °C		Greater than 300 °C
Maximum temperature	1 minute rolling average less than 1,100 °C	11-12 Minutes	Less than 1,100 °C
Action	Engulfing fire exposure continues		Engulfing fire exposure continues
Minimum temperature	1-minute rolling average greater than 800 °C		1-minute rolling average Greater than 800 °C
Maximum temperature	1 minute rolling average less than 1,100 °C	12 Minutes - end of test	1-minute rolling average less than 1,100 °C

(d) Documenting results of the fire test

The arrangement of the fire is recorded in sufficient detail to ensure the rate of heat input to the test article is reproducible. The results include the elapsed time from ignition of the fire to the start of venting through the TPRD(s), and the maximum pressure and time of evacuation until a pressure of less than 1 MPa is reached. Thermocouple temperatures and container pressure are recorded at intervals of every 10 sec or less during the test. Any failure to maintain specified minimum temperature requirements based on the 1-minute rolling averages invalidates the test result. Any failure to maintain specified maximum temperature requirements based on the 1-minute rolling averages invalidates the test result only if the test article failed during the test.

5.2. Engulfing fire test:

The test unit is the compressed hydrogen storage system. The storage system is filled with compressed hydrogen gas at 100 per cent NWP (+2/-0 MPa). The container is positioned horizontally with the container bottom approximately 100 mm above the fire source. Metallic shielding is used to prevent direct flame impingement on container valves, fittings, and/or pressure relief devices. The metallic shielding is not in direct contact with the specified fire protection system (pressure relief devices or container valve).

A uniform fire source of 1.65 m length provides direct flame impingement on the container surface across its entire diameter. The test shall continue until the container fully vents (until the container pressure falls below 0.7 MPa). Any failure or inconsistency of the fire source during a test shall invalidate the result.

Flame temperatures shall be monitored by at least three thermocouples suspended in the flame approximately 25 mm below the bottom of the container. Thermocouples may be attached to steel cubes up to 25 mm on a side. Thermocouple temperature and the container pressure shall be recorded every 30 seconds during the test.

Within five minutes after the fire is ignited, an average flame temperature of not less than 590 °C (as determined by the average of the two thermocouples recording the highest temperatures over a 60 second interval) is attained and maintained for the duration of the test.

If the container is less than 1.65 m in length, the centre of the container shall be positioned over the centre of the fire source. If the container is greater than 1.65 m in length, then if the container is fitted with a pressure relief device at one end, the fire source shall commence at the opposite end of the container. If the container is greater than 1.65 m in length and is fitted with pressure relief devices at both ends, or at more than one location along the length of the container, the centre of the fire source shall be centred midway between the pressure relief devices that are separated by the greatest horizontal distance.

The container shall vent through a pressure relief device without bursting.

## Annex 4

### Test procedures for specific components for the compressed hydrogen storage system

#### 1. TPRD Qualification Performance Tests

Testing is performed with hydrogen gas having gas quality compliant with ISO 14687-2/SAE J2719. All tests are performed at ambient temperature 20 (±5) °C unless otherwise specified. The TPRD qualification performance tests are specified as follows (see also Appendix 1):

##### 1.1. Pressure cycling test.

Five TPRD units undergo 11,000 internal pressure cycles with hydrogen gas having gas quality compliant with ISO 14687-2/SAE J2719. The first five pressure cycles are between 2 (±1) MPa and 150 per cent NWP (±1 MPa); the remaining cycles are between 2 (±1) MPa and 125 per cent NWP (±1 MPa). The first 1,500 pressure cycles are conducted at a TPRD temperature of 85 °C or higher. The remaining cycles are conducted at a TPRD temperature of 55 (±5) °C. The maximum pressure cycling rate is ten cycles per minute. Following this test, the pressure relief device shall comply the requirements of Leak test (Annex 4, paragraph 1.8.), Flow rate test (Annex 4, paragraph 1.10.) and Bench top activation test (Annex 4 paragraph 1.9.).

##### 1.2. Accelerated life test.

Eight TPRD units undergo testing; three at the manufacturer's specified activation temperature,  $T_{act}$ , and five at an accelerated life temperature,  $T_{life} = 9.1 \times T_{act}^{0.503}$ . The TPRD is placed in an oven or liquid bath with the temperature held constant (±1 °C). The hydrogen gas pressure on the TPRD inlet is 125 per cent NWP (±1 MPa). The pressure supply may be located outside the controlled temperature oven or bath. Each device is pressured individually or through a manifold system. If a manifold system is used, each pressure connection includes a check valve to prevent pressure depletion of the system when one specimen fails. The three TPRDs tested at  $T_{act}$  shall activate in less than ten hours. The five TPRDs tested at  $T_{life}$  shall not activate in less than 500 hours.

##### 1.3. Temperature cycling test

- (a) An unpressurized TPRD is placed in a liquid bath maintained at -40 °C or lower at least two hours. The TPRD is transferred to a liquid bath maintained at +85 °C or higher within five minutes, and maintained at that temperature at least two hours. The TPRD is transferred to a liquid bath maintained at -40 °C or lower within five minutes;
- (b) Step (a) is repeated until 15 thermal cycles have been achieved;
- (c) With the TPRD conditioned for a minimum of two hours in the -40 °C or lower liquid bath, the internal pressure of the TPRD is cycled with hydrogen gas between 2 MPa (+1/-0 MPa) and 80 per cent NWP (+2/-0 MPa) for 100 cycles while the liquid bath is maintained at -40 °C or lower;

- (d) Following the thermal and pressure cycling, the pressure relief device shall comply with the requirements of Leak test (Annex 4, paragraph 1.8.), except that the Leak test shall be conducted at  $-40\text{ }^{\circ}\text{C}$  ( $+5/-0\text{ }^{\circ}\text{C}$ ). After the Leak test, the TPRD shall comply with the requirements of Bench top activation test (Annex 4, paragraph 1.9.) and then Flow rate test (Annex 4, paragraph 1.10.).

1.4. Salt corrosion resistance test

Two TPRD units are tested. Any non-permanent outlet caps are removed. Each TPRD unit is installed in a test fixture in accordance with the manufacturer's recommended procedure so that external exposure is consistent with realistic installation. Each unit is exposed for 500 hours to a salt spray (fog) test as specified in ASTM B117 (Standard Practice for Operating Salt Spray (Fog) Apparatus) except that in the test of one unit, the pH of the salt solution shall be adjusted to  $4.0 \pm 0.2$  by the addition of sulphuric acid and nitric acid in a 2:1 ratio, and in the test of the other unit, the pH of the salt solution shall be adjusted to  $10.0 \pm 0.2$  by the addition of sodium hydroxide. The temperature within the fog chamber is maintained at  $30-35\text{ }^{\circ}\text{C}$ .

Following these tests, each pressure relief device shall comply with the requirements of Leak test (Annex 3, paragraph 6.1.8.), Flow rate test (Annex 3, paragraph 6.1.10.) and Bench top activation test (Annex 3, paragraph 6.1.9.).

1.5. Vehicle environment test

Resistance to degradation by external exposure to automotive fluids is determined by the following test:

- (a) The inlet and outlet connections of the TPRD are connected or capped in accordance with the manufacturers installation instructions. The external surfaces of the TPRD are exposed for 24 hours at  $20 (\pm 5)\text{ }^{\circ}\text{C}$  to each of the following fluids:
  - (i) Sulphuric acid (19 per cent solution by volume in water);
  - (ii) Sodium hydroxide (25 per cent solution by weight in water);
  - (iii) Ammonium nitrate (28 per cent by weight in water); and
  - (iv) Windshield washer fluid (50 per cent by volume methyl alcohol and water).

The fluids are replenished as needed to ensure complete exposure for the duration of the test. A distinct test is performed with each of the fluids. One component may be used for exposure to all of the fluids in sequence.

- (b) After exposure to each fluid, the component is wiped off and rinsed with water;
- (c) The component shall not show signs of physical degradation that could impair the function of the component, specifically: cracking, softening, or swelling. Cosmetic changes such as pitting or staining are not failures. At the conclusion of all exposures, the unit(s) shall comply with the requirements of Leak test (Annex 4, paragraph 1.8.), Flow rate test (Annex 4, paragraph 1.10.) and Bench top activation test (Annex 4, paragraph 1.9.).

1.6. Stress corrosion cracking test.

For TPRDs containing components made of a copper-based alloy (e.g. brass), one TPRD unit is tested. All copper alloy components exposed to the atmosphere shall be degreased and then continuously exposed for ten days to a moist ammonia-air mixture maintained in a glass chamber having a glass cover.

Aqueous ammonia having a specific gravity of 0.94 is maintained at the bottom of the glass chamber below the sample at a concentration of at least 20 ml per litre of chamber volume. The sample is positioned 35 ( $\pm 5$ ) mm above the aqueous ammonia solution and supported in an inert tray. The moist ammonia-air mixture is maintained at atmospheric pressure at 35 ( $\pm 5$ ) °C. Copper-based alloy components shall not exhibit cracking or delaminating due to this test.

1.7. Drop and vibration test

- (a) Six TPRD units are dropped from a height of 2 m at ambient temperature ( $20 \pm 5$  °C) onto a smooth concrete surface. Each sample is allowed to bounce on the concrete surface after the initial impact. One unit is dropped in six orientations (opposing directions of 3 orthogonal axes: vertical, lateral and longitudinal). If each of the six dropped samples does not show visible exterior damage that indicates that the part is unsuitable for use, it shall proceed to step (b);
- (b) Each of the six TPRD units dropped in step (a) and one additional unit not subjected to a drop are mounted in a test fixture in accordance with manufacturer's installation instructions and vibrated 30 minutes along each of the three orthogonal axes (vertical, lateral and longitudinal) at the most severe resonant frequency for each axis. The most severe resonant frequencies are determined using an acceleration of 1.5 g and sweeping through a sinusoidal frequency range of 10 to 500 Hz within 10 minutes. The resonance frequency is identified by a pronounced increase in vibration amplitude. If the resonance frequency is not found in this range, the test shall be conducted at 40 Hz. Following this test, each sample shall not show visible exterior damage that indicates that the part is unsuitable for use. It shall subsequently comply with the requirements of Leak test (Annex 4, paragraph 1.8.), Flow rate test (Annex 4, paragraph 1.10.) and Bench top activation test (Annex 4, paragraph 1.9.).

1.8. Leak test

A TPRD that has not undergone previous testing is tested at ambient, high and low temperatures without being subjected to other design qualification tests. The unit is held for one hour at each temperature and test pressure before testing. The three temperature test conditions are:

- (a) Ambient temperature: condition the unit at 20 ( $\pm 5$ ) °C; test at 5 per cent NWP (+0/-2 MPa) and 150 per cent NWP (+2/-0 MPa);
- (b) High temperature: condition the unit at 85 °C or higher; test at 5 per cent NWP (+0/-2 MPa) and 150 per cent NWP (+2/-0 MPa);
- (c) Low temperature: condition the unit at -40 °C or lower; test at 5 per cent NWP (+0/-2 MPa) and 100 per cent NWP (+2/-0 MPa).



Additional units undergo leak testing as specified in other tests in Annex 4, paragraph 1. with uninterrupted exposure at the temperature specified in those tests.

At all specified test temperatures, the unit is conditioned for one minute by immersion in a temperature controlled fluid (or equivalent method). If no bubbles are observed for the specified time period, the sample passes the test. If bubbles are detected, the leak rate is measured by an appropriate method. The total hydrogen leak rate shall be less than 10 Nml/hr.

1.9. Bench top activation test

Two new TPRD units are tested without being subjected to other design qualification tests in order to establish a baseline time for activation. Additional pre-tested units (pre-tested according to Annex 4, paragraphs 1.1., 1.3., 1.4., 1.5. or 1.7.) undergo bench top activation testing as specified in other tests in Annex 4, paragraph 1.

- (a) The test setup consists of either an oven or chimney which is capable of controlling air temperature and flow to achieve  $600 (\pm 10)$  °C in the air surrounding the TPRD. The TPRD unit is not exposed directly to flame. The TPRD unit is mounted in a fixture according to the manufacturer's installation instructions; the test configuration is to be documented;
- (b) A thermocouple is placed in the oven or chimney to monitor the temperature. The temperature remains within the acceptable range for two minutes prior to running the test;
- (c) The pressurized TPRD unit is inserted into the oven or chimney, and the time for the device to activate is recorded. Prior to insertion into the oven or chimney, one new (not pre-tested) TPRD unit is pressurized to no more than 25 per cent NWP (the pre-tested); TPRD units are pressurized to no more than 25 per cent NWP; and one new (not pre-tested) TPRD unit is pressurized to 100 per cent NWP;
- (d) TPRD units previously subjected to other tests in Annex 4, paragraph 1. shall activate within a period no more than two minutes longer than the baseline activation time of the new TPRD unit that was pressurized to up to 25 per cent NWP;
- (e) The difference in the activation time of the two TPRD units that had not undergone previous testing shall be no more than 2 minutes.

1.10. Flow rate test

- (a) Eight TPRD units are tested for flow capacity. The eight units consist of three new TPRD units and one TPRD unit from each of the following previous tests: Annex 4, paragraphs 1.1., 1.3., 1.4., 1.5. and 1.7.;
- (b) Each TPRD unit is activated according to Annex 4, paragraph 1.9. After activation and without cleaning, removal of parts, or reconditioning, each TPRD unit is subjected to flow test using hydrogen, air or an inert gas;
- (c) Flow rate testing is conducted with a gas inlet pressure of  $2 (\pm 0.5)$  MPa. The outlet is at ambient pressure. The inlet temperature and pressure are recorded;

- (d) Flow rate is measured with accuracy within  $\pm 2$  per cent. The lowest measured value of the eight pressure relief devices shall not be less than 90 per cent of the highest flow value.

2. Tests for check valve and shut-off valve

Testing shall be performed with hydrogen gas having gas quality compliant with ISO 14687-2/SAE J2719. All tests are performed at ambient temperature  $20 (\pm 5)$  °C unless otherwise specified. The check valve and shut-off valve qualification performance tests are specified as follows (see also Appendix 2):

2.1. Hydrostatic strength test

The outlet opening in components is plugged and valve seats or internal blocks are made to assume the open position. One unit is tested without being subjected to other design qualification tests in order to establish a baseline burst pressure, other units are tested as specified in subsequent tests of Annex 4, paragraph 2.

- (a) A hydrostatic pressure of 250 per cent NWP ( $+2/-0$  MPa) is applied to the inlet of the component for three minutes. The component is examined to ensure that rupture has not occurred;
- (b) The hydrostatic pressure is then increased at a rate of less than or equal to 1.4 MPa/sec until component failure. The hydrostatic pressure at failure is recorded. The failure pressure of previously tested units shall be no less than 80 per cent of the failure pressure of the baseline, unless the hydrostatic pressure exceeds 400 per cent NWP.

2.2. Leak test

One unit that has not undergone previous testing is tested at ambient, high and low temperatures without being subjected to other design qualification tests. The three temperature test conditions are:

- (a) Ambient temperature: condition the unit at  $20 (\pm 5)$  °C; test at 5 per cent NWP ( $+0/-2$  MPa) and 150 per cent NWP ( $+2/-0$  MPa);
- (b) High temperature: condition the unit at 85 °C or higher; test at 5 per cent NWP ( $+0/-2$  MPa) and 150 per cent NWP ( $+2/-0$  MPa);
- (c) Low temperature: condition the unit at -40 °C or lower; test at 5 per cent NWP ( $+0/-2$  MPa) and 100 per cent NWP ( $+2/-0$  MPa).

Additional units undergo leak testing as specified in other tests in Annex 4, paragraph 2. with uninterrupted exposure at the temperatures specified in those tests.

The outlet opening is plugged with the appropriate mating connection and pressurized hydrogen is applied to the inlet. At all specified test temperatures, the unit is conditioned for one minute by immersion in a temperature controlled fluid (or equivalent method). If no bubbles are observed for the specified time period, the sample passes the test. If bubbles are detected, the leak rate is measured by an appropriate method. The leak rate shall not exceed 10 Nml/hr of hydrogen gas.

2.3. Extreme temperature pressure cycling test

- (a) The total number of operational cycles is 11,000 for the check valve and 50,000 for the shut-off valve. The valve unit are installed in a test fixture corresponding to the manufacturer's specifications for installation. The operation of the unit is continuously repeated using hydrogen gas at all specified pressures.

An operational cycle shall be defined as follows:

- (i) A check valve is connected to a test fixture and 100 per cent NWP (+2/-0 MPa) is applied in six step pulses to the check valve inlet with the outlet closed. The pressure is then vented from the check valve inlet. The pressure is lowered on the check valve outlet side to less than 60 per cent NWP prior to the next cycle;
- (ii) A shut-off valve is connected to a test fixture and pressure is applied continuously to the both the inlet and outlet sides.

An operational cycle consists of one full operation and reset.

- (b) Testing is performed on a unit stabilized at the following temperatures:

(i) Ambient temperature cycling. The unit undergoes operational (open/closed) cycles at 125 per cent NWP (+2/-0 MPa) through 90 per cent of the total cycles with the part stabilized at 20 ( $\pm 5$ ) °C. At the completion of the ambient temperature operational cycles, the unit shall comply with the ambient temperature leak test specified in Annex 4, paragraph 2.2.;

(ii) High temperature cycling. The unit then undergoes operational cycles at 125 per cent NWP (+2/-0 MPa) through 5 per cent of the total operational cycles with the part stabilized at 85 °C or higher. At the completion of the 85 °C cycles, the unit shall comply with the high temperature (85 °C) leak test specified in Annex 4, paragraph 2.2.;

(iii) Low temperature cycling. The unit then undergoes operational cycles at 100 per cent NWP (+2/-0 MPa) through 5 per cent of the total cycles with the part stabilized at -40 °C or lower. At the completion of the -40 °C operational cycles, the unit shall comply with the low temperature (-40 °C) leak test specified in Annex 4, paragraph 2.2.

- (c) Check valve chatter flow test: Following 11,000 operational cycles and leak tests in Annex 4, paragraph 2.3.(b), the check valve is subjected to 24 hours of chatter flow at a flow rate that causes the most chatter (valve flutter). At the completion of the test the check valve shall comply with the ambient temperature leak test (Annex 4, paragraph 2.2.) and the strength test (Annex 4, paragraph 2.1.).

2.4. Salt corrosion resistance test

The component is supported in its normally installed position and exposed for 500 hours to a salt spray (fog) test as specified in ASTM B117 (Standard Practice for Operating Salt Spray (Fog) Apparatus). The temperature within the fog chamber is maintained at 30 — 35 °C). The saline solution consists of 5 per cent sodium chloride and 95 per cent distilled water, by weight.

Immediately after the corrosion test, the sample is rinsed and gently cleaned of salt deposits, examined for distortion, and then shall comply with the requirements of:

- (a) The component shall not show signs of physical degradation that could impair the function of the component, specifically: cracking, softening or swelling. Cosmetic changes such as pitting or staining are not failures;
- (b) The ambient temperature leak test (Annex 4, paragraph 2.2.);
- (c) The hydrostatic strength test (Annex 4, paragraph 2.1.).

2.5. Vehicle environment test

Resistance to degradation by exposure to automotive fluids is determined by the following test.

- (a) The inlet and outlet connections of the valve unit are connected or capped in accordance with the manufacturers installation instructions. The external surfaces of the valve unit are exposed for 24 hours at 20 ( $\pm 5$ ) °C to each of the following fluids:
  - (i) Sulphuric acid -19 per cent solution by volume in water;
  - (ii) Sodium hydroxide -25 per cent solution by weight in water;
  - (iii) Ammonium nitrate -28 per cent by weight in water; and
  - (iv) Windshield washer fluid (50 per cent by volume methyl alcohol and water).

The fluids are replenished as needed to ensure complete exposure for the duration of the test. A distinct test is performed with each of the fluids. One component may be used for exposure to all of the fluids in sequence.

- (b) After exposure to each chemical, the component is wiped off and rinsed with water;
- (c) The component shall not show signs of physical degradation that could impair the function of the component, specifically: cracking, softening, or swelling. Cosmetic changes such as pitting or staining are not failures. At the conclusion of all exposures, the unit(s) shall comply with the requirements of the ambient temperature leakage test (Annex 4, paragraph 2.2.) and Hydrostatic Strength Test (Annex 4, paragraph 2.1.).

2.6. Atmospheric exposure test

The atmospheric exposure test applies to qualification of check valve and automatic shut-off valves if the component has non-metallic materials exposed to the atmosphere during normal operating conditions.

- (a) All non-metallic materials that provide a fuel containing seal, and that are exposed to the atmosphere, for which a satisfactory declaration of properties is not submitted by the applicant, shall not crack or show visible evidence of deterioration after exposure to oxygen for 96 hours at 70 °C at 2 MPa in accordance with ASTM D572 (Standard Test Method for Rubber- Deterioration by Heat and Oxygen);

- (b) All elastomers shall demonstrate resistance to ozone by one or more of the following:
  - (i) Specification of elastomer compounds with established resistance to ozone;
  - (ii) Component testing in accordance with ISO 1431/1, ASTM D1149, or equivalent test methods.

2.7. Electrical Tests

The electrical tests apply to qualification of the automatic shut-off valve; they do not apply to qualification of check valves.

- (a) Abnormal voltage test. The solenoid valve is connected to a variable DC voltage source. The solenoid valve is operated as follows:
  - (i) An equilibrium (steady state temperature) hold is established for one hour at 1.5 times the rated voltage;
  - (ii) The voltage is increased to two times the rated voltage or 60 volts, whichever is less, and held for one minute;
  - (iii) Any failure shall not result in external leakage, open valve or unsafe conditions such as smoke, fire or melting.

The minimum opening voltage at NWP and room temperature shall be less than or equal to 9 V for a 12 V system and less than or equal to 18 V for a 24 V system.

- (b) Insulation resistance test. 1,000 V D.C. is applied between the power conductor and the component casing for at least two seconds. The minimum allowable resistance for that component is 240 k $\Omega$ .

2.8. Vibration test

The valve unit is pressurized to its 100 per cent NWP (+2/-0 MPa) with hydrogen, sealed at both ends, and vibrated for 30 minutes along each of the three orthogonal axes (vertical, lateral and longitudinal) at the most severe resonant frequencies. The most severe resonant frequencies are determined by acceleration of 1.5 g with a sweep time of 10 minutes within a sinusoidal frequency range of 10 to 40 Hz. If the resonance frequency is not found in this range the test is conducted at 40Hz. Following this test, each sample shall not show visible exterior damage that indicates that the performance of the part is compromised. At the completion of the test, the unit shall comply with the requirements of the ambient temperature leak test specified in Annex 4, paragraph 2.2.

2.9. Stress corrosion cracking test

For the valve units containing components made of a copper-based alloy (e.g. brass), one valve unit is tested. The valve unit is disassembled, all copper-based alloy components are degreased and then the valve unit is reassembled before it is continuously exposed for ten days to a moist ammonia-air mixture maintained in a glass chamber having a glass cover.

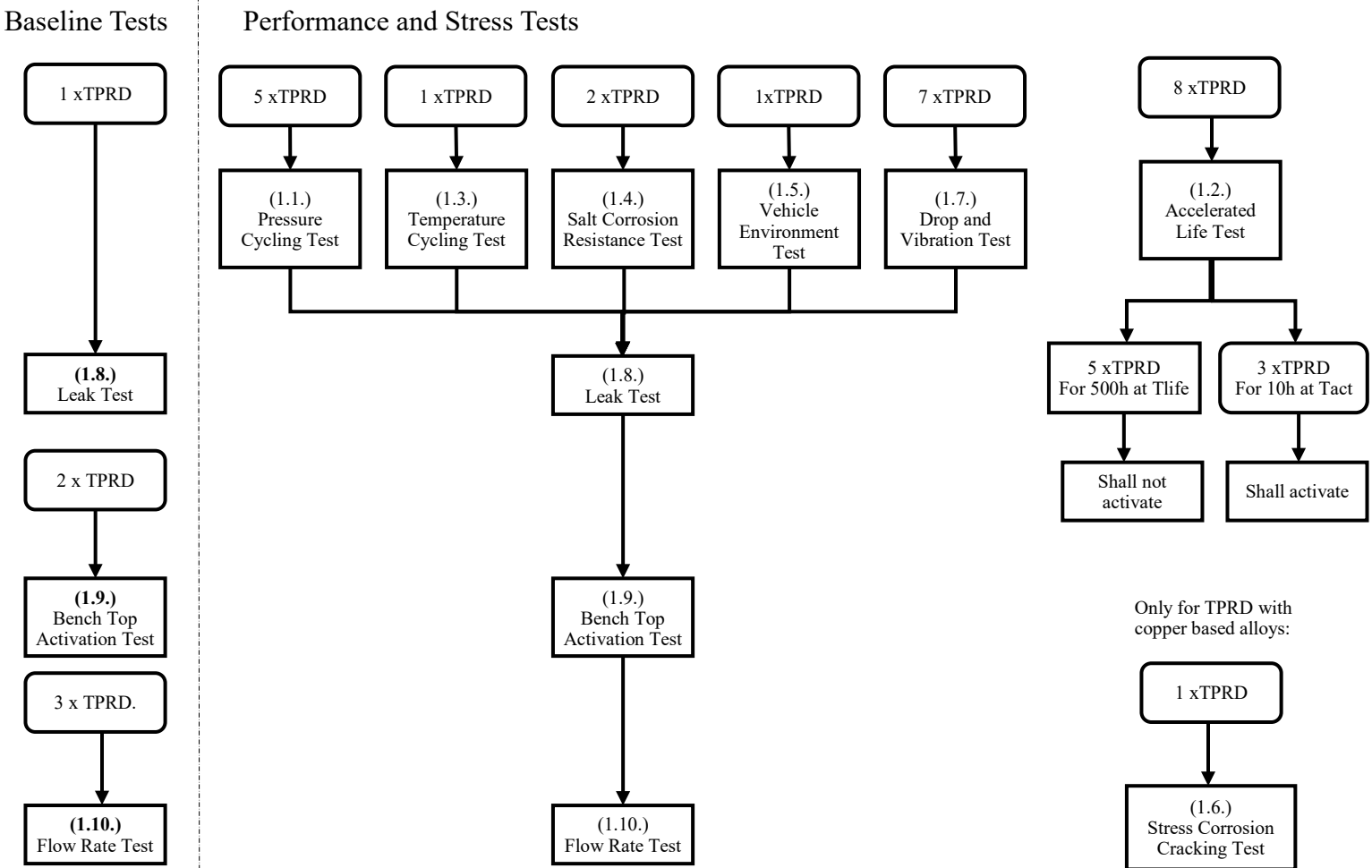
Aqueous ammonia having a specific gravity of 0.94 is maintained at the bottom of the glass chamber below the sample at a concentration of at least 20 ml per litre of chamber volume. The sample is positioned 35 ( $\pm 5$ ) mm above the aqueous ammonia solution and supported in an inert tray. The moist ammonia-air mixture is maintained at atmospheric pressure at 35 ( $\pm 5$ ) °C. Copper-based alloy components shall not exhibit cracking or delaminating due to this test.

2.10. Pre-cooled hydrogen exposure test

The valve unit is subjected to pre-cooled hydrogen gas at -40 °C or lower at a flow rate of 30 g/sec at external temperature of 20 ( $\pm 5$ ) °C for a minimum of three minutes. The unit is de-pressurized and re-pressurized after a two minute hold period. This test is repeated ten times. This test procedure is then repeated for an additional ten cycles, except that the hold period is increased to 15 minutes. The unit shall then comply with the requirements of the ambient temperature leak test specified in Annex 4, paragraph 2.2.

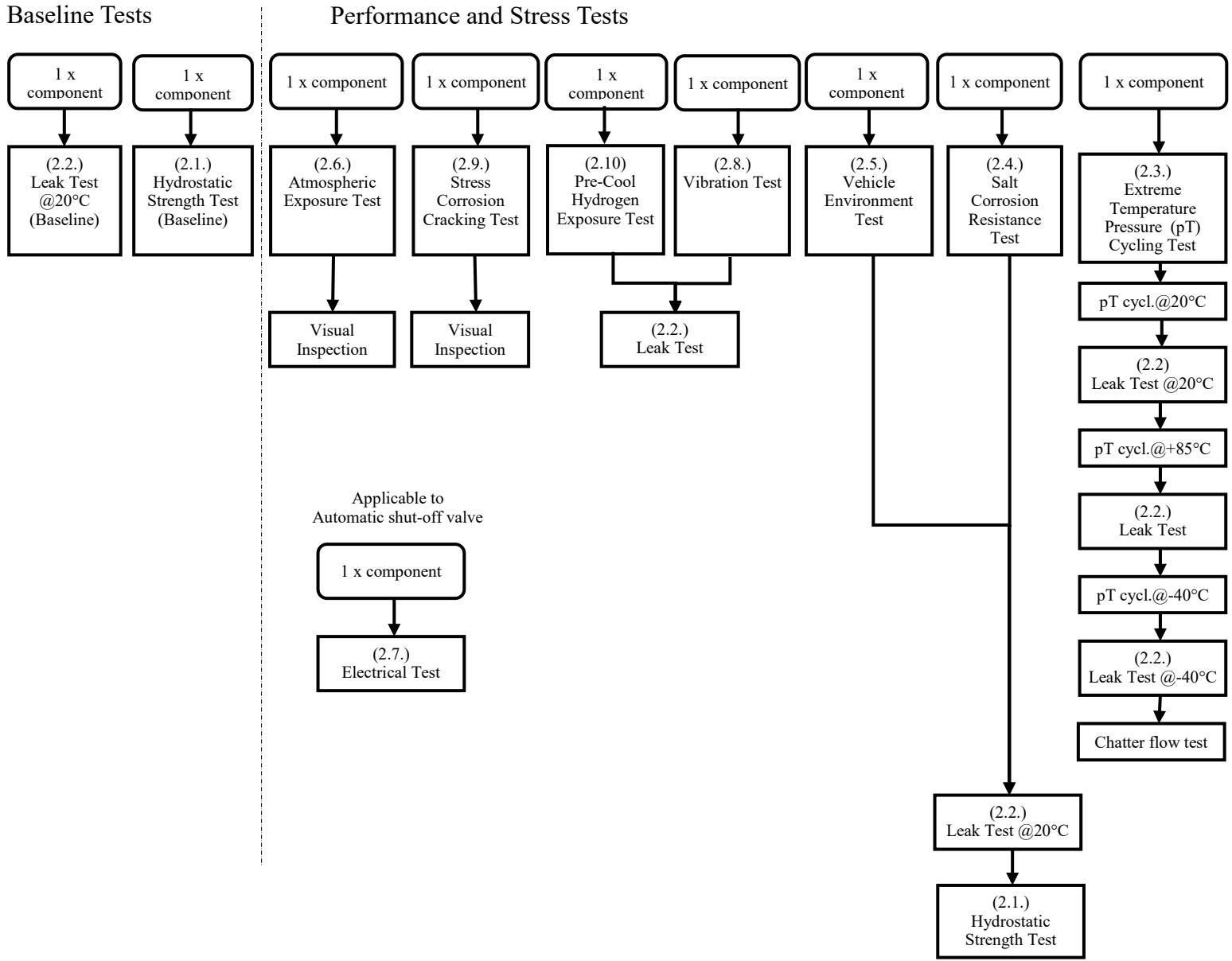
Annex 4 - Appendix 1

Overview of TPRD tests



**Annex 4 - Appendix 2**

**Overview of check valve and automatic shut-off valve tests**





## Annex 5

### Test procedures for a vehicle fuel system incorporating the compressed hydrogen storage system

1. Compliance test for single failure conditions  
Either test procedure of Annex 5, paragraph 1.1. or paragraph 1.2. shall be executed:
  - 1.1. Test procedure for vehicle equipped with hydrogen gas leakage detectors
    - 1.1.1. Test condition
      - 1.1.1.1. Test vehicle: The propulsion system of the test vehicle is started, warmed up to its normal operating temperature, and left operating for the test duration. If the vehicle is not a fuel cell vehicle, it is warmed up and kept idling. If the test vehicle has a system to stop idling automatically, measures are taken so as to prevent the engine from stopping.
      - 1.1.1.2. Test gas: Two mixtures of air and hydrogen gas: 3.0 per cent concentration (or less) of hydrogen in the air to verify function of the warning, and 4.0 per cent concentration (or less) of hydrogen in the air to verify the shut-down function. The proper concentrations are selected based on the recommendation (or the detector specification) by the manufacturer.
    - 1.1.2. Test method
      - 1.1.2.1. Preparation for the test: The test is conducted without any influence of wind by appropriate means such as:
        - (a) A test gas induction hose is attached to the hydrogen gas leakage detector;
        - (b) The hydrogen leak detector is enclosed with a cover to make gas stay around hydrogen leak detector.
      - 1.1.2.2. Execution of the test
        - (a) Test gas is blown to the hydrogen gas leakage detector;
        - (b) Proper function of the warning system is confirmed when tested with the gas to verify function of the warning;
        - (c) The main shut-off valve is confirmed to be closed when tested with the gas to verify function of the shut-down. For example, the monitoring of the electric power to the shut-off valve or of the sound of the shut-off valve activation may be used to confirm the operation of the main shut-off valve of the hydrogen supply.
  - 1.2. Test procedure for integrity of enclosed spaces and detection systems.
    - 1.2.1. Preparation:
      - 1.2.1.1. The test is conducted without any influence of wind.
      - 1.2.1.2. Special attention is paid to the test environment as during the test, flammable mixtures of hydrogen and air may occur.

- 1.2.1.3. Prior to the test the vehicle is prepared to allow remotely controllable hydrogen releases from the hydrogen system. The number, location and flow capacity of the release points downstream of the main hydrogen shut-off valve are defined by the vehicle manufacturer taking worst case leakage scenarios under single failure condition into account. As a minimum, the total flow of all remotely controlled releases shall be adequate to trigger demonstration of the automatic "warning" and hydrogen shut-off functions.
- 1.2.1.4. For the purpose of the test, a hydrogen concentration detector is installed where hydrogen gas may accumulate most in the passenger compartment (e.g. near the headliner) when testing for compliance with paragraph 7.1.4.2. of this Regulation and hydrogen concentration detectors are installed in enclosed or semi enclosed volumes on the vehicle where hydrogen can accumulate from the simulated hydrogen releases when testing for compliance with paragraph 7.1.4.3. of this Regulation (see Annex 5, paragraph 1.2.1.3.).
- 1.2.2. Procedure:
  - 1.2.2.1. Vehicle doors, windows and other covers are closed.
  - 1.2.2.2. The propulsion system is started, allowed to warm up to its normal operating temperature and left operating at idle for the test duration.
  - 1.2.2.3. A leak is simulated using the remote controllable function.
  - 1.2.2.4. The hydrogen concentration is measured continuously until the concentration does not rise for 3 minutes. When testing for compliance with paragraph 7.1.4.3 of this Regulation, the simulated leak is then increased using the remote controllable function until the main hydrogen shut-off valve is closed and the tell-tale warning signal is activated. The monitoring of the electric power to the shut-off valve or of the sound of the shut-off valve activation may be used to confirm the operation of the main shut-off valve of the hydrogen supply.
  - 1.2.2.5. When testing for compliance with paragraph 7.1.4.2. of this Regulation, the test is successfully completed if the hydrogen concentration in the passenger compartment does not exceed 1.0 per cent. When testing for compliance with paragraph 7.1.4.3. of this Regulation, the test is successfully completed if the tell-tale warning and shut-off function are executed at (or below) the levels specified in paragraph 7.1.4.3. of this Regulation; otherwise, the test is failed and the system is not qualified for vehicle service.
2. Compliance test for the vehicle exhaust system
  - 2.1. The power system of the test vehicle (e.g. fuel cell stack or engine) is warmed up to its normal operating temperature.
  - 2.2. The measuring device is warmed up before use to its normal operating temperature.
  - 2.3. The measuring section of the measuring device is placed on the centre line of the exhaust gas flow within 100 mm from the exhaust point of discharge external to the vehicle.
  - 2.4. The exhaust hydrogen concentration is continuously measured during the following steps:
    - (a) The power system is shut-down;
    - (b) Upon completion of the shut-down process, the power system is immediately started;

- (c) After a lapse of one minute, the power system is turned off and measurement continues until the power system shut-down procedure is completed.
  - 2.5. The measurement device shall have a measurement response time of less than 300 milliseconds.
  - 3. Compliance test for fuel line leakage
    - 3.1. The power system of the test vehicle (e.g. fuel cell stack or engine) is warmed up and operating at its normal operating temperature with the operating pressure applied to fuel lines.
    - 3.2. Hydrogen leakage is evaluated at accessible sections of the fuel lines from the high-pressure section to the fuel cell stack (or the engine), using a gas leak detector or a leak detecting liquid, such as soap solution.
    - 3.3. Hydrogen leak detection is performed primarily at joints
    - 3.4. When a gas leak detector is used, detection is performed by operating the leak detector for at least 10 seconds at locations as close to fuel lines as possible.
    - 3.5. When a leak detecting liquid is used, hydrogen gas leak detection is performed immediately after applying the liquid. In addition, visual checks are performed a few minutes after the application of liquid to check for bubbles caused by trace leaks.
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