Option 1

Proposal for a new UN regulation on Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety-related performance of vehicles and systems fuelled with liquefied hydrogen

Submitted by the Kingdom of the Netherlands and the International Organization of Motor Vehicle Manufacturers (OICA)

Contents

1. Scope

This Regulation applies to[(1)]:

1.1. Part I - Liquefied hydrogen storage systems (LHSS) for hydrogen-fuelled vehicles on their safety-related performance.

1.2. Part II - Specific components for liquefied hydrogen storage systems (LHSS) for hydrogen-fuelled vehicles on their safety-related performance.

1.3. Part III - Hydrogen-fuelled vehicles of category M and N[(2)] incorporating liquefied hydrogen storage system (LHSS) on its safety-related performance.

2. Definitions

For the purpose 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)

(1) This Regulation does not cover the electrical safety of electric power train, the material compatibility and hydrogen embrittlement of the vehicle fuel system, and the post-crash fuel system integrity in the event of full width frontal impact and rear impact.

(2) As defined in the Consolidated Resolution on the Construction of Vehicles (R.E.3.), document ECE/TRANS/WP.29/78/Rev.8, para. 2. — https://unece.org/transport/vehicle-regulations/wp29/resolutions

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.

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 or liquefied 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 14687:2025 and SAE J2719_202003.

2.13. "*Liquefied Hydrogen Storage System (LHSS)"* means liquefied hydrogen storage container(s) PRDs, shut-off device, a boil-off system and the interconnection piping (if any) and fittings between the above components.

2.14. "*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.

2.15. "*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.

2.16. "*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.

2.17. "*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.

2.18. "*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.

2.19. "*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.

2.20. "*Rupture*" or "*burst*" both mean to come apart suddenly and violently, break open or fly into pieces due to the force of internal pressure.

2.21. "*Safety relief valve*" means a pressure relief device that opens at a preset pressure level and can re-close.

2.22. "*Service life*" (of a compressed hydrogen container) means the time frame during which service (usage) is authorized.

2.23. "*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.

2.24. "*Single failure"* means a failure caused by a single event, including any consequential failures resulting from this failure.

2.25. "*Thermally activated Pressure Relief Device (TPRD)*" means a non- reclosing PRD that is activated by temperature to open and release hydrogen gas.

2.26. "*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 or liquefied;

(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.

2.27. "*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 or liquefied;

(c) the sort of component: (T)PRD, check-valve or shut-off valve, and

(d) the structure, materials and essential characteristics.

2.28. "*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.

2.29. "*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. The application for approval of a vehicle or component type with regard to the safety-related performance of hydrogen fuelled vehicles shall be submitted by the manufacturer or by his authorized representative.

3.2. It shall be accompanied by the documents mentioned below and include the following particulars:

3.2.1. Detailed description of the vehicle or component type on the safety-related performance of hydrogen fuelled vehicles.

3.3. A sufficient number of vehicles and/or components representatives of the type to be approved shall be submitted to the Technical Service conducting the approval tests.

4. Approval

4.1. If the vehicle or component type submitted for approval pursuant to this Regulation meets the requirements of the relevant part of this Regulation, approval of that vehicle, system or component shall be granted.

4.2. An approval number shall be assigned to each type approved: its first two digits (00 for the Regulation in its initial form) shall indicate the series of amendments incorporating the most recent major technical amendments made to the 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 or 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 [2];

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 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 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 liquefied hydrogen storage system, the approval mark shall be placed close to or on the container.

5. Part I – Specifications of the Liquefied Hydrogen Storage System (LHSS)

This part specifies the requirements for the liquefied hydrogen storage system.

The boundaries of the LHSS are defined by the interfaces which can isolate the stored liquefied (and/or gaseous) hydrogen from the remainder of the fuel system and the environment. All components located within this boundary are subject to the requirements defined in this paragraph. - Figure 1 shows a typical LHSS. The closure devices shall include the following functions, which may be combined:

(a) Automatic shut-off device;

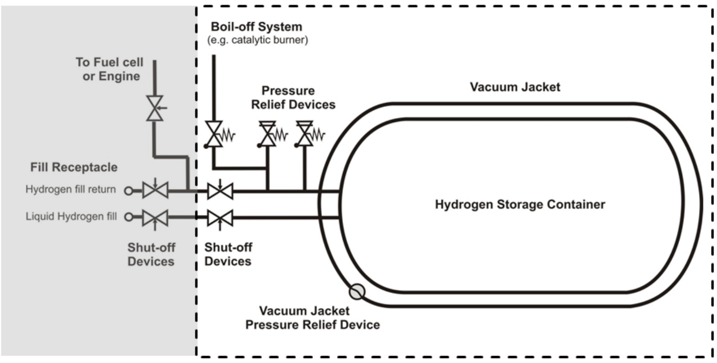
(b) Boil-off system;

(c) Pressure Relief Device (PRD).

Figure 1

Typical liquefied hydrogen storage system

[2] As defined in Annex 3 to the Consolidated Resolution on the Construction of Vehicles (R.E.3), document ECE/TRANS/WP.29/78/Rev. 8 (https://unece.org/transport/vehicle-regulations/wp29/resolutions)



The liquefied hydrogen storage system shall qualify for the performance test requirements specified in this paragraph. The manufacturer shall specify a Maximum Allowable Working Pressure (MAWP).

The test elements within these performance requirements are summarized in Table 1.

Table 1

Overview of performance requirements

Paragraph 5.1. Verification of baseline metrics 5.1.1. Proof pressure 5.1.2. Baseline initial burst pressure, performed on the inner container 5.1.3. Baseline Pressure cycle life
Paragraph 5.2. Verification of expected on-road performance 5.2.1. Boil-off 5.2.2. Leak 5.2.3. Vacuum loss
Paragraph 5.3. Verification for service-terminating conditions: Bonfire test
Paragraph 5.2.4. Requirements for pressure relief device and shut-off device

5.1. Verification of baseline metrics

5.1.1. Proof pressure

A system is pressurized to a pressure $p_{test} \geq 1.3$ (MAWP ± 0.1 MPa) in accordance with the test procedure in Annex 3, paragraph 1.1. without visible deformation, degradation of container pressure, or detectable leakage.

5.1.2. Baseline initial burst pressure

The burst test is performed in accordance with the test procedure in Annex 3, paragraph 1.2. on one sample of the inner container that is not integrated in its outer jacket and not insulated.

The burst pressure shall be at least equal to the burst pressure used for the mechanical calculations. For steel containers that is either:

(a) Maximum Allowable Working Pressure (MAWP) (in MPa) plus 0.1 MPa multiplied by 3.25;

or

(b) Maximum Allowable Working Pressure (MAWP) (in MPa) plus 0.1 MPa multiplied by 1.5 and multiplied by R_m/R_p, where R_m is the minimum ultimate tensile strength of the container material and Rp (minimum yield strength) is 1.0 for austenitic steels and R_p is 0.2 for other steels.

5.1.3. Baseline pressure cycle life

When using metallic containers and/or metallic vacuum jackets, the manufacturer shall either provide a calculation in order to demonstrate that the container is designed according to current regional legislation or accepted standards (e.g. in US the ASME Boiler and Pressure Vessel Code, in Europe EN 1251-1:2000 and EN 1251-2:2000 and in all other countries an applicable regulation for the design of metallic pressure containers), or define and perform suitable tests (including Annex 3, paragraph 1.3.) that prove the same level of safety compared to a design supported by calculation according to accepted standards.

For non-metallic containers and/or vacuum jackets, in addition to the tests in Annex 3, paragraph 1.3., suitable tests shall be designed by the manufacturer to prove the same level of safety as a metallic container.

5.2. Verification for expected on-road performance

5.2.1. Boil-off

The boil-off test is performed on a liquefied hydrogen storage system equipped with all components as described in paragraph 5. (Figure 1). The test is performed on a system filled with liquid hydrogen in accordance with the test procedure in Annex 3, paragraph 2.1. and shall demonstrate that the boil-off system limits the pressure in the inner storage container to below the maximum allowable working pressure.

5.2.2. Leak

After the boil-off test in paragraph 2.1. of Annex 3, the system is kept at boil-off pressure and the total discharge rate due to leakage shall be measured in accordance with the test procedure in Annex 3, paragraph 2.2. The maximum allowable discharge from the hydrogen storage system is R*150 Nml/min where

R = $(V_{width}+1)*(V_{height}+0.5)*(V_{length}+1)/30.4$ and V_{width}, V_{height}, V_{length} are the vehicle width, height, length (m), respectively.

5.2.3. Vacuum loss

The vacuum loss test is performed on a liquefied hydrogen storage system equipped with all components as described in paragraph 5. (Figure 1). The test is performed on a system filled with liquid hydrogen in accordance with the test procedure in Annex 3, paragraph 2.3. and shall demonstrate that both primary and secondary pressure relief devices limit the pressure to the values specified in Annex 3, paragraph 2.3. if vacuum pressure is lost.

5.3. Verification of service-terminating conditions: Bonfire test

The function of the pressure relief devices and the absence of rupture under the following service terminating conditions shall be demonstrated in accordance with the test procedures provided in Annex 3, paragraph 3.

A hydrogen storage system is filled to half-full liquid level and exposed to fire in accordance with the test procedure of Annex 3, paragraph 3. The pressure relief device(s) shall release the contained gas in a controlled manner without rupture.

For steel containers, the test is successfully completed when the requirements on the pressure limits for the pressure relief devices as described in Annex 3, paragraph 3. are fulfilled. For other container materials, an equivalent level of safety shall be demonstrated.

5.4. 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, MAWP, fuel type (i.e. "LH_2" for liquid hydrogen).

6. Part II – Specifications of the specific components for liquefied hydrogen storage system (LHSS)

6.1. Pressure relief device qualification requirements

The pressure relief device shall meet the following performance qualification requirements:

(a) Pressure test (Annex 4, paragraph 1. test procedure);

(b) External leakage test (Annex 4, paragraph 2. test procedure);

(c) Operational test (Annex 4, paragraph 4. test procedure);

(d) Corrosion resistance test (Annex 4, paragraph 5. test procedure);

(e) Temperature cycle test (Annex 4, paragraph 8. test procedure).

6.2. Shut-off device qualification requirements

The shut-off device shall meet the following performance qualification requirements:

(a) Pressure test (Annex 4, paragraph 1. test procedure);

(b) External leakage Test (Annex 4, paragraph 2. test procedure);

(c) Endurance test (Annex 4, paragraph 3. test procedure);

(d) Corrosion resistance test (Annex 4, paragraph 5. test procedure);

(e) Resistance to dry-heat test (Annex 4, paragraph 6. test procedure);

(f) Ozone ageing test (Annex 4, paragraph 7. test procedure);

(g) Temperature cycle test (Annex 4, paragraph 8. test procedure);

(h) Flex line cycle test (Annex 4, paragraph 9. test procedure).

7. Part III – Specifications of vehicle fuel system incorporating LHSS

This part specifies requirements for the integrity of the hydrogen fuel delivery system, which includes the liquefied hydrogen storage system, piping, joints, and components in which hydrogen is present. The fuelling receptacle label shall designate liquid hydrogen as the fuel type. Test procedures are given in Annex 5.

7.1. In-use fuel system integrity

7.1.1. Fuelling receptacle requirements

7.1.1.1. A label shall be affixed close to the fuelling receptacle; for instance, inside a refilling hatch, showing the following information: fuel type (e.g. "LH_2" for liquefied hydrogen), NWP, MFP, date of removal from service of containers.

7.1.1.2. 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.

7.1.1.3. 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.

7.1.1.4. If appropriate, the geometry of the fuelling receptacle of liquefied hydrogen gas vehicles may be at the manufacturer's discretion and in agreement with the technical service in absence of a standard.

7.2. In-use fuel system integrity

7.2.1. 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 over-pressure protection shall comply with the installation verification referred to in Annex 5, paragraph 6.

7.2.2. Hydrogen discharge systems

7.2.2.1. Pressure relief systems

Pressure relief devices (such as a burst disc) shall comply with the installation verification referred to in Annex 5, paragraph 6. and may be used outside the hydrogen storage system. The hydrogen gas discharge from other pressure relief devices shall not be directed:

(a) towards exposed electrical terminals, exposed electrical switches or other ignition sources;

(b) into or towards the vehicle passenger or luggage compartments;

(c) into or towards any vehicle wheel housing; and

(d) towards hydrogen gas containers.

7.2.2.2. Vehicle exhaust system

7.2.2.2.1. The vehicle exhaust system shall comply with the test for the vehicle exhaust system referred to in Annex 5, paragraph 4.

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

(a) Not exceed 4 % average by volume during any moving three-second time interval during normal operation including start-up and shutdown; and

(b) Not exceed 8 % at any time.

7.2.3. Protection against flammable conditions: single failure conditions

7.2.3.1. Hydrogen leakage and/or permeation from the hydrogen storage system shall not directly vent into the passenger, luggage, or cargo compartments, or to any enclosed or semi-enclosed spaces within the vehicle that contains unprotected ignition sources.

7.2.3.2. Any single failure downstream of the main hydrogen shut off valve shall not result in any level of a hydrogen concentration in anywhere in the passenger compartment according to test procedure referred to in Annex 5, paragraph 3.2.

7.2.3.3. If, during operation, a single failure results in a hydrogen concentration exceeding 3 % by volume in air in the enclosed or semi-enclosed spaces of the vehicle, then a warning shall be provided (paragraph 7.2.3.5.). If the hydrogen concentration exceeds 4 % by volume in the air in the enclosed or semi-enclosed spaces of the vehicle, the main shutoff valve shall be closed to isolate the storage system. (Annex 5, paragraph 3. test procedure).

7.2.3.4. 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 5. test procedure).

7.2.3.5. 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;

(b) Yellow in colour if the detection system malfunctions (e.g. circuit disconnection, short-circuit, sensor fault). It shall be red in compliance with paragraph 7.2.3.3.

(c) When illuminated, shall be visible to the driver under both daylight and night time driving conditions; and

(d) Remains illuminated when 3 % concentration or detection system malfunction) exists and the master control is in the 'on' position or the propulsion system is otherwise activated.

7.3. Post-crash fuel system integrity

The vehicle fuel system shall comply with the following requirements after the vehicle crash tests in accordance with the following UN Regulations by also applying the test procedures prescribed in Annex 5 to this Regulation.

(a) Frontal impact test procedures in accordance with either Regulation No. 12, or Regulation No. 94, Annex 3 and Regulation No. 137, Annex 3 only to the extent where the Regulations apply as prescribed in their scope; and

(b) Lateral impact test procedures in accordance with UN Regulation No. 95, Annex 4.

At the request of the manufacturer, for vehicles not in the scope of these UN Regulations and that are derived from M_1 or N_1 vehicle categories, they may be tested in accordance with the crash test procedures in these UN Regulations.

This requirement is deemed to be met if the vehicle equipped with LHSS is approved in accordance with UN Regulation No. 94 (05 series of amendments or later) or UN Regulation No. 137 (03 series of amendments or later) for frontal impact and UN Regulation No. 95 (06 series of amendments or later) for lateral impact, as applicable in the scope of aforementioned crash regulations.

Commented [VDA1]: The abbreviation is included in the definitions.

Where one or more of these crash tests are not required, the LHSS, including the safety devices affixed to it shall be installed in such a way that the following accelerations can be absorbed without breaking of the fixation or loosening of the filled LHSS container(s):

Vehicle of categories M_1 and N_1:

(a) 20 g in forward and rearward direction of travel; and

(b) 8 g horizontally perpendicular to the direction of travel.

Vehicles of categories M_2 and N_2:

(a) 10 g in forward direction of travel; and

(b) 5 g horizontally perpendicular to the direction of travel.

Vehicles of categories M_3 and N_3:

(a) 6.6 g in the forward direction of travel; and

(b) 5 g horizontally perpendicular to the direction of travel.

Any substitute mass used shall be representative for a fully equipped and filled LHSS container/assembly.

7.3.1. Fuel leakage limit

The volumetric flow of hydrogen gas leakage shall not exceed an average of 118 NL per minute for 60 minutes after the crash as determined in accordance with Annex 5, paragraph 1.

7.3.2. Concentration limit in enclosed spaces

Hydrogen gas leakage shall not result in a hydrogen concentration in the air greater than 4 % by volume in the passenger and luggage compartments (Annex 5, paragraph 2. test procedures). The requirement is satisfied if it is confirmed that the shut-off valve of the storage system has closed within 5 seconds of the crash and no leakage from the storage system.

7.3.3. Container Displacement

The storage container(s) shall remain attached to the vehicle at a minimum of one attachment point.

7.4. Flammable materials used in the vehicle shall be protected from liquefied air that may condense on elements of the fuel system.

7.5. The insulation of the components shall prevent liquefaction of the air in contact with the outer surfaces, unless a system is provided for collecting and vaporizing the liquefied air. The materials of the components nearby shall be compatible with an atmosphere enriched with oxygen.

8. Vehicle identification

8.1. On vehicles of the categories M_2/N_2 and M_3/N_3, equipped with a liquefied hydrogen storage system, labels shall be installed as specified in Annex 6.

These labels shall be placed on the front of the vehicle and on the left side as well as on the right side of the vehicle; for the side in vicinity of a front door, if available. If there is no front door available, the label must be placed on the first third of the vehicle length. In addition, for vehicles of category M_2 and M_3, a label shall be fixed to the rear of the vehicle."

~~8.2. In the case of hydrogen vehicles of categories M_2 and M_3, labels shall be installed on the front and rear of the vehicle, in the vicinity of the fuelling receptacle and to the side of each door or set of doors as specified in Annex 6.~~

8.3. In the case of hydrogen vehicles of categories N_2 and N_3, labels shall be installed on the front and rear of the vehicle and in the vicinity of the fuelling receptacle as specified in Annex 6.

9. Modification of type and extension of approval

9.1. 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 9.1.1. (Revision) and, if applicable, the procedure contained in paragraph 9.1.2. (Extension).

9.1.1. 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/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.

9.1.2. 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.

9.2. 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.

9.3. The Competent Authority issuing the extension of approval shall assign a serial number to each communication form drawn up for such an extension.

10. Conformity of production

10.1 Procedures concerning conformity of production shall conform to the general provisions defined in Schedule 1 to the Agreement (E/ECE/324-E/ECE/TRANS/505/Rev.3).

10.2. A vehicle, 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 8. above;

10.3. The competent 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.

11. Penalties for non-conformity of production

11.1. 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 10. above are not complied with.

11.2. 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.

12. 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.

13. Names and addresses of the 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.

14. Transitional provisions

Contracting Parties applying this Regulation may continue to require the proof of compliance (i.e. data-sheet including chemical composition) to their national/regional provisions on the material compatibility and hydrogen embrittlement, which were already implemented within their territory at the time of entry into force of this Regulation, until relevant technical requirements are established as a part of global registry under the 1998 Agreement such as global technical regulation No. 13.

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

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[1]......
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)
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

[1] Delete where not applicable (there are cases where nothing needs to be deleted when more than one entry is applicable).

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:..

3.9.3.9. Description and drawing:..

3.9.3.10. 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:...

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

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:..

Model - III

Information document No … on the type-approval of a vehicle with regard to the safety-related performance of hydrogen-fuelled vehicles

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[1]: ....
0.3.1. Location of that marking: ....
0.4. Category of vehicle[2]: ....
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[3]
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):...

[1] 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. […]).
[2] As defined in the Consolidated Resolution on the Construction of Vehicles (R.E.3.), document ECE/TRANS/WP.29/78/Rev.8, para. 2. - https://unece.org/transport/vehicle-regulations/wp29/resolutions
[3] Delete where not applicable (there are cases where nothing needs to be deleted when more than one entry is applicable).

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

Communication

(Maximum format: A4 (210 x 297 mm)

[1]

issued by: Name of administration:
....
....
....

concerning [2]: Approval granted

Approval extended

Approval refused

Approval withdrawn

Production definitively discontinued

of a type of vehicle/component with regard to the safety-related performance of hydrogen-fuelled vehicles pursuant to Regulation No. XYZ

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/component:[2]...

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

[2] Delete what does not apply.

6. Date of submission of vehicle/component for approval:[2] ....

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: [2]..

11. Place:...

12. Date:..

13. Signature:...

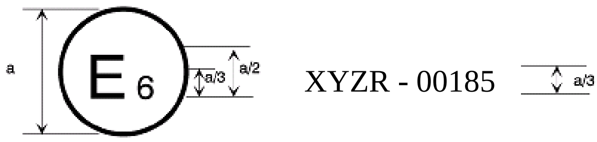
14. The information document annexed to this communication:..

15. Any remarks:...

Annex 2

Arrangements of the approval marks

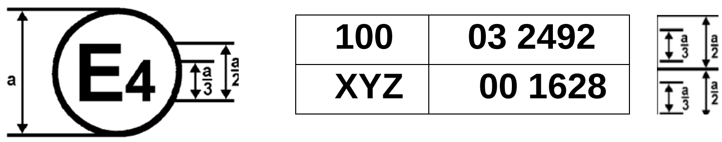
Model A (See paragraphs 4.4. to 4.4.2. of this Regulation)



a = 8 mm min

The above approval mark affixed to a vehicle/component shows that the vehicle/system type concerned has been approved in Belgium (E6) for its the safety-related performance of hydrogen-fuelled vehicles pursuant to Regulation No. XYZ. The first two digits of the approval number indicate that the approval was granted in accordance with the requirements of Regulation No. XYZ 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 (E4) pursuant to Regulations Nos. XYZ and 100. * *The approval number indicates that, at the dates when the respective approvals were granted, Regulation No. 100 was amended by the 03 series of amendments and Regulation No. XYZ was still in its original form.

* The latter number is given only as an example.

Annex 3

Test procedures for LHSS design qualification

1. Verification tests for Baseline metrics

1.1. Proof pressure test

The inner container and the pipe work situated between the inner container and the outer jacket shall withstand an inner pressure test at room temperature according to the following requirements.

The test pressure p_{test} is defined by the manufacturer and shall fulfil the following requirements:

$p_{test} \geq 1.3$ (MAWP ± 0.1 MPa)

(a) For metallic containers, either p_{test} is equal to or greater than the maximum pressure of the inner container during fault management (as determined in Annex 3, paragraph 2.3.) or the manufacturer proves by calculation that at the maximum pressure of the inner container during fault management no yield occurs;

(b) For non-metallic containers, p_{test} is equal to or greater than the maximum pressure of the inner container during fault management (as determined in Annex 3, paragraph 2.3.).

The test is conducted according to the following procedure:

(a) The test is conducted on the inner storage container and the interconnecting pipes between inner storage container and vacuum jacket before the outer jacket is mounted;

(b) The test is either conducted hydraulically with water or a glycol/water mixture, or alternatively with gas. The container is pressurized to test pressure ptest at an even rate and kept at that pressure for at least 10 minutes;

(c) The test is done at ambient temperature. In the case of using gas to pressurize the container, the pressurization is done in a way that the container temperature stays at or around ambient temperature.

The test is passed successfully if, during the first 10 minutes after applying the proof pressure, no visible permanent deformation, no visible degradation in the container pressure and no visible leakage are detectable.

1.2. Baseline initial burst pressure

The test is conducted according to the following procedure:

(a) The test is conducted on the inner container at ambient temperature;

(b) The test is conducted hydraulically with water or a water/glycol mixture;

(c) The pressure is increased at a constant rate, not exceeding 0.5 MPa/min until burst or leakage of the container occurs;

(d) When MAWP is reached there is a wait period of at least ten minutes at constant pressure, during which time the deformation of the container can be checked;

(e) The pressure is recorded or written during the entire test.

For steel inner containers, the test is passed successfully if at least one of the two passing criteria described in paragraph 5.1.2. of this Regulation is fulfilled. For inner containers made out of an aluminium alloy or other material, a passing criterion shall be defined which guarantees at least the same level of safety compared to steel inner containers.

1.3. Baseline pressure cycle life

Containers and/or vacuum jackets are pressure cycled with a number of cycles at least three times the number of possible full pressure cycles (from the lowest to highest operating pressure) for an expected on-road performance. The number of pressure cycles is defined by the manufacturer under consideration of operating pressure range, size of the storage and, respectively, maximum number of refuellings and maximum number of pressure cycles under extreme usage and storage conditions. Pressure cycling is conducted between atmospheric pressure and MAWP at liquid nitrogen temperatures, e.g. by filling the container with liquid nitrogen to certain level and alternately pressurizing and depressurizing it with (pre-cooled) gaseous nitrogen or helium.

2. Verification for expected on-road performance

2.1. Boil-off test

The test is conducted according to the following procedure:

(a) For pre-conditioning, the container is fuelled with liquid hydrogen to the specified maximum filling level. Hydrogen is subsequently extracted until it meets half filling level, and the system is allowed to completely cool down for at least 24 hours and a maximum of 48 hours;

(b) The container is filled to the specified maximum filling level;

(c) The container is pressurized until boil-off pressure is reached;

(d) The test lasts for at least another 48 hours after boil-off started and is not terminated before the pressure stabilizes. Pressure stabilization has occurred when the average pressure does not increase over a two hour period.

The pressure of the inner container is recorded or written during the entire test. The test is passed successfully if the following requirements are fulfilled:

(a) The pressure stabilizes and stays below MAWP during the whole test;

(b) The pressure relief devices are not allowed to open during the whole test.

The pressure of the inner container shall be recorded or written during the entire test. The test is passed when the following requirements are fulfilled:

(a) The pressure shall stabilize and stay below MAWP during the whole test;

(b) The pressure relief devices are not allowed to open during the whole test.

2.2. Leak test

The test shall be conducted according to the procedure described in Annex 4, paragraph 2.

2.3. Vacuum loss test

The first part of the test is conducted according to the following procedure:

(a) The vacuum loss test is conducted with a completely cooled-down container (according to the procedure in Annex 3, paragraph 2.1.);

(b) The container is filled with liquid hydrogen to the specified maximum filling level;

(c) The vacuum enclosure is flooded with air at an even rate to atmospheric pressure;

(d) The test is terminated when the first pressure relief device does not open any more.

The pressure of the inner container and the vacuum jacket is recorded or written during the entire test. The opening pressure of the first safety device is recorded or written. The first part of test is passed if the following requirements are fulfilled:

(a) The first pressure relief device opens below or at MAWP and limit the pressure to not more than 110 per cent of the MAWP;

(b) The first pressure relief device does not open at pressure above MAWP;

(c) The secondary pressure relief device does not open during the entire test.

After passing the first part, the test shall be repeated subsequently to re-generation of the vacuum and cool-down of the container as described above.

(a) The vacuum is re-generated to a value specified by the manufacturer. The vacuum shall be maintained at least 24 hours. The vacuum pump may stay connected until the time directly before the start of the vacuum loss;

(b) The second part of the vacuum loss test is conducted with a completely cooled-down container (according to the procedure in Annex 3, paragraph 2.1.);

(c) The container is filled to the specified maximum filling level;

(d) The line downstream the first pressure relief device is blocked and the vacuum enclosure is flooded with air at an even rate to atmospheric pressure;

(e) The test is terminated when the second pressure relief device does not open any more.

The pressure of the inner container and the vacuum jacket is recorded or written during the entire test. For steel containers the second part of the test is passed if the secondary pressure relief device does not open below 110 per cent of the set pressure of the first pressure relief device and limits the pressure in the container to a maximum 136 per cent of the MAWP if a safety valve is used, or, 150 per cent of the MAWP if a burst disk is used as the secondary pressure relief device. For other container materials, an equivalent level of safety shall be demonstrated.

3. Verification test for service-terminating performance due to fire

The tested liquefied hydrogen storage system shall be representative of the design and the manufacturing of the type to be homologated. Its manufacturing shall be completely finished and it shall be mounted with all its equipment.

The first part of the test is conducted according to the following procedure:

(a) The bonfire test is conducted with a completely cooled-down container (according to the procedure in Annex 3, paragraph 2.1.);

(b) The container contained during the previous 24 hours a volume of liquid hydrogen at least equal to half of the water volume of the inner container;

(c) The container is filled with liquid hydrogen so that the quantity of liquid hydrogen measured by the mass measurement system is half of the maximum allowed quantity that may be contained in the inner container;

(d) A fire burns 0.1 m underneath the container. The length and the width of the fire exceed the plan dimensions of the container by 0.1 m. The temperature of the fire is at least 590 ºC. The fire shall continue to burn for the duration of the test;

(e) The pressure of the container at the beginning of the test is between 0 MPa and 0.01 MPa at the boiling point of hydrogen in the inner container;

(f) The test shall continue until the storage pressure decreases to or below the pressure at the beginning of the test, or alternatively in case the first PRD is a re-closing type, the test shall continue until the safety device has opened for a second time;

(g) The test conditions and the maximum pressure reached within the container during the test are recorded in a test certificate signed by the manufacturer and the technical service.

The test is passed if the following requirements are fulfilled:

(a) The secondary pressure relief device is not operated below 110 per cent of the set pressure of the primary pressure relief device;

(b) The container shall not burst and the pressure inside the inner container shall not exceed the permissible fault range of the inner container.

The permissible fault range for steel containers is as follows:

(a) If a safety valve is used as secondary pressure relief device, the pressure inside the container does not exceed 136 per cent of the MAWP of the inner container;

(b) If a burst disc is used outside the vacuum area as secondary pressure relief device, the pressure inside the container is limited to 150 per cent of the MAWP of the inner container;

(c) If a burst disc is used inside the vacuum area as secondary pressure relief device, the pressure inside the container is limited to 150 per cent of the MAWP ± 0.1 MPa of the inner container.

For other materials, an equivalent level of safety shall be demonstrated.

Annex 4

Test procedures for specific component for LHSS

The test procedures for pressure relief devices (paragraph 6.1. of this Regulation) and shut-off valves (paragraph 6.2. of this Regulation) are described below:

Testing shall be performed with hydrogen gas having gas quality compliant with ISO 14687:2025/SAE J2719_202003. All tests shall be performed at ambient temperature 20(±5) °C unless otherwise specified.

1. Pressure test

A hydrogen containing component shall withstand without any visible evidence of leak or deformation a test pressure of 150 per cent MAWP with the outlets of the high-pressure part plugged. The pressure shall subsequently be increased from 150 per cent to 300 per cent MAWP. The component shall not show any visible evidence of rupture or cracks.

The pressure supply system shall be equipped with a positive shut-off valve and a pressure gauge having a pressure range of not less than 150 per cent and no more than 200 per cent of the test pressure; the accuracy of the gauge shall be 1 per cent of the pressure range.

For components requiring a leakage test, this test shall be performed prior to the pressure test.

2. External leakage test

A component shall be free from leakage through stem or body seals or other joints and shall not show evidence of porosity in casting when tested as described in Annex 4, paragraph 3.3. at any gas pressure between zero and its MAWP.

The test shall be performed on the same equipment at the following conditions:

(a) At ambient temperature;

(b) At the minimum operating temperature or at liquid nitrogen temperature after sufficient conditioning time at this temperature to ensure thermal stability;

(c) At the maximum operating temperature after sufficient conditioning time at this temperature to ensure thermal stability.

During this test, the equipment under test shall be connected to a source of gas pressure. A positive shut-off valve and a pressure gauge having a pressure range of not less than 150 per cent and not more than 200 per cent of the test pressure shall be installed in the pressure supply piping; the accuracy of the gauge shall be 1 per cent of the pressure range. The pressure gauge shall be installed between the positive shut-off valve and the sample under test.

Throughout the test, the sample shall be tested for leakage, with a surface-active agent without formation of bubbles or measured with a leakage rate less than 216 Nml/hr.

3. Endurance test

3.1. A component shall be capable of conforming to the applicable leakage test requirements of Annex 4, paragraphs 2. and 9., after being subjected to 20,000 operation cycles.

3.2. The appropriate tests for external leakage and seat leakage, as described in Annex 4, paragraphs 2. and 9. shall be carried out immediately following the endurance test.

3.3. The shut-off valve shall be securely connected to a pressurized source of dry air or nitrogen and subjected to 20,000 operation cycles. A cycle shall consist of one opening and one closing of the component within a period of not less than 10 ± 2 seconds.

3.4. The component shall be operated through 96 per cent of the number of specified cycles at ambient temperature and at the MAWP of the component. During the off cycle the downstream pressure of the test fixture shall be allowed to decay to 50 per cent of the MAWP of the component.

3.5. The component shall be operated through 2 per cent of the total cycles at the maximum material temperature (-40 °C to +85 °C) after sufficient conditioning time at this temperature to ensure thermal stability and at MAWP. The component shall comply with Annex 4, paragraphs 2. and 9. at the appropriate maximum material temperature (-40 °C to +85 °C) at the completion of the high temperature cycles.

3.6. The component shall be operated through 2 per cent of the total cycles at the minimum material temperature (-40 °C to +85 °C) but not less than the temperature of liquid nitrogen after sufficient conditioning time at this temperature to ensure thermal stability and at the MAWP of the component. The component shall comply with Annex 4, paragraphs 2. and 9. at the appropriate minimum material temperature (-40 °C to +85 °C) at the completion of the low temperature cycles.

4. Operational test

The operational test shall be carried out in accordance with EN 13648-1:2009 or EN 13648-2:2002. The specific requirements of the standard are applicable.

5. Corrosion resistance test

Metallic hydrogen components shall comply with the leakage tests referred to in Annex 4, paragraphs 2. and 9. after being submitted to 144 hours salt spray test according to ISO 9227:2022 with all connections closed.

A copper or brass hydrogen containing component shall comply with the leakage tests referred to in Annex 4, paragraphs 2. and 9. and after being submitted to 24 hours immersion in ammonia according to ISO 6957:1988 with all connections closed.

6. Resistance to dry-heat test

The test shall be carried out in compliance with ISO 188:2023. The test piece shall be exposed to air at a temperature equal to the maximum operating temperature for 168 hours. The change in tensile strength shall not exceed ±25 per cent. The change in ultimate elongation shall not exceed the following values:

- maximum increase 10 per cent;

- maximum decrease 30 per cent.

7. Ozone ageing Test

The test shall be in compliance with ISO 1431-1:2024. The test piece, which shall be stressed to 20 per cent elongation, shall be exposed to air at +40 °C with an ozone concentration of 50 parts per hundred million during 120 hours.

No cracking of the test piece is allowed.

8. Temperature cycle test

A non-metallic part containing hydrogen shall comply with the leakage tests referred to in Annex 4, paragraphs 2. and 9. after having been submitted to a 96-hour temperature cycle from the minimum operating temperature up to the maximum operating temperature with a cycle time of 120 minutes, under MAWP.

9. Flex line cycle test

Any flexible fuel line shall be capable of conforming to the applicable leakage test requirements referred to in Annex 4, paragraph 2., after being subjected to 6,000 pressure cycles.

The pressure shall change from atmospheric pressure to the MAWP of the container within less than five seconds, and after a time of at least five seconds, shall decrease to atmospheric pressure within less than five seconds.

The appropriate test for external leakage, as referred to in Annex 4, paragraph 2., shall be carried out immediately following the endurance test.

Annex 5

Test procedures for a vehicle fuel system incorporating LHSS

The test procedures for vehicle fuel systems incorporating LHSS according to paragraphs 1., 2. and 7. of this annex apply only to vehicles of categories M_1 and N_1 that are subjected to one or more crash tests.

1. Post-crash liquefied hydrogen storage system leak test

Prior to conducting the crash test, instrumentation is installed in the hydrogen storage system to perform the required pressure and temperature measurements if the standard vehicle does not already have instrumentation with the required accuracy.

The storage system is then purged, if necessary, following manufacturer directions to remove impurities from the container before filling the storage system with compressed hydrogen or helium gas. Since the storage system pressure varies with temperature, the targeted fill pressure is a function of the temperature. The target pressure shall be determined from the following equation:

$P_{target} = NWP \times (273 + T_o) / 288$

where NWP is the nominal working pressure (MPa), T_o is the ambient temperature to which the storage system is expected to settle, and P_{target} is the targeted fill pressure after the temperature settles.

The container is filled to a minimum of 95 % of the targeted fill pressure and allowed to settle (stabilize) prior to conducting the crash test.

The main stop valve and shut-off valves for hydrogen gas, located in the downstream hydrogen gas piping, are kept open immediately prior to the impact.

1.1. Post-crash leak test - compressed hydrogen storage system filled with compressed hydrogen

The hydrogen gas pressure, P_0 (MPa), and temperature, T_0 (°C), is measured immediately before the impact and then at a time interval, Δt (min), after the impact. The time interval, Δt, starts when the vehicle comes to rest after the impact and continues for at least 60 minutes. The time interval, Δt, is increased, if necessary, in order to accommodate measurement accuracy for a storage system with a large volume operating up to 70 MPa; in that case, Δt can be calculated from the following equation:

$\Delta t = V_{CHSS} \times NWP /1\,000 \times ((-\,0.027 \times NWP + 4) \times R_s - 0.21) - 1.7 \times R_s$

where $R_s = P_s$ / NWP, P_s is the pressure range of the pressure sensor (MPa), NWP is the Nominal Working Pressure (MPa), V_{CHSS} is the volume of the compressed hydrogen storage system (L), and Δt is the time interval (min). If the calculated value of Δt is less than 60 minutes, Δt is set to 60 minutes.

The initial mass of hydrogen in the storage system can be calculated as follows:

$P_o' = P_o \times 288 / (273 + T_0)$

$P_o' = -\,0.0027 \times (P_0')^2 + 0.75 \times P_0' + 0.5789$

$M_o = \rho_o' \times V_{CHSS}$

Correspondingly, the final mass of hydrogen in the storage system, M_f, at the end of the time interval, Δt, can be calculated as follows:

$P_f' = P_f \times 288 / (273 + T_f)$

$\rho_f' = -0.0027 \times (P_f')^2 + 0.75 \times P_f' + 0.5789$

$M_f = \rho_f' \times V_{CHSS}$

where P_f is the measured final pressure (MPa) at the end of the time interval, and T_f is the measured final temperature (°C).

The average hydrogen flow rate over the time interval (that shall be less than the criteria in paragraph 7.3.1.) is therefore:

$V_{H2} = (M_f – M_o) / \Delta t \times 22.41 / 2.016 \times (P_{target} / P_o)$

where V_{H2} is the average volumetric flow rate (NL/min) over the time interval and the term (P_{target} / P_o) is used to compensate for differences between the measured initial pressure, P_o, and the targeted fill pressure P_{target}.

1.2. Post-crash leak test - Compressed hydrogen storage system filled with compressed helium

The helium gas pressure, P_0 (MPa), and temperature T_0 (°C), are measured immediately before the impact and then at a predetermined time interval after the impact. The time interval, Δt, starts when the vehicle comes to rest after the impact and continues for at least 60 minutes.

The time interval, Δt, shall be increased, if necessary, in order to accommodate measurement accuracy for a storage system with a large volume operating up to 70MPa; in that case, Δt can be calculated from the following equation:

$\Delta t = V_{CHSS} \times NWP / 1\,000 \times ((-0.028 \times NWP + 5.5) \text{ x } R_s - 0.3) - 2.6 \times R_s$

where $R_s = P_s / NWP$, P_s is the pressure range of the pressure sensor (MPa), NWP is the Nominal Working Pressure (MPa), V_{CHSS} is the volume of the compressed hydrogen storage system (L), and Δt is the time interval (min). If the value of Δt is less than 60 minutes, Δt is set to 60 minutes.

The initial mass of hydrogen in the storage system is calculated as follows:

$P_o' = P_o \times 288 / (273 + T_0)$

$\rho_o' = -0.0043 \times (P_0')^2 + 1.53 \times P_0' + 1.49$

$M_o = \rho_o' \times V_{CHSS}$

The final mass of hydrogen in the storage system at the end of the time interval, Δt, is calculated as follows:

$P_f' = P_f \times 288 / (273 + T_f)$

$\rho_f' = -0.0043 \times (P_f')^2 + 1.53 \times P_f' + 1.49$

$M_f = \rho_f' \times V_{CHSS}$

where P_f is the measured final pressure (MPa) at the end of the time interval, and T_f is the measured final temperature (°C).

The average helium flow rate over the time interval is therefore

$V_{He} = (M_f – M_o) / \Delta t \times 22.41 / 4.003 \times (P_o / P_{target})$

where V_{He} is the average volumetric flow rate (NL/min) over the time interval and the term P_o / P_{target} is used to compensate for differences between the measured initial pressure (P_o) and the targeted fill pressure (P_{target}).

Conversion of the average volumetric flow of helium to the average hydrogen flow is done with the following expression:

$V_{H2} = V_{He} / 0.75$

where V_{H2} is the corresponding average volumetric flow of hydrogen (that shall be less than the criteria in paragraph 7.3.1. of this Regulation to pass).

2. Post-crash concentration test for enclosed spaces

2.1. The measurements are recorded in the crash test that evaluates potential hydrogen (or helium) leakage as determined in accordance with paragraph 1.

2.2. Sensors are selected to measure either the build-up of the hydrogen or helium gas or the reduction in oxygen (due to displacement of air by leaking hydrogen/helium).

2.3. Sensors are calibrated to traceable references to ensure an accuracy of ±5 % at the targeted criteria of 4 % hydrogen or 3 % helium by volume in air, and a full-scale measurement capability of at least 25 % above the target criteria. The sensor shall be capable of a 90 % response to a full-scale change in concentration within 10 seconds.

2.4. Prior to the crash impact, the sensors are located in the passenger and luggage compartments of the vehicle as follows:

(a) At a distance within 250 mm of the headliner above the driver’s seat or near the top centre the passenger compartment;

(b) At a distance within 250 mm of the floor in front of the rear (or rear most) seat in the passenger compartment;

(c) At a distance within 100 mm of the top of luggage compartments within the vehicle that are not directly affected by the particular crash impact to be conducted.

2.5. The sensors are securely mounted on the vehicle structure or seats and protected for the planned crash test from debris, air bag exhaust gas and projectiles. The measurements following the crash are recorded by instruments located within the vehicle or by remote transmission.

2.6. The vehicle may be located either outdoors in an area protected from the wind and possible solar effects or indoors in a space that is large enough or ventilated to prevent the build-up of hydrogen to more than 10 % of the targeted criteria in the passenger, luggage, and cargo compartments.

2.7. Post-crash data collection in enclosed spaces commences when the vehicle comes to a rest. Data from the sensors are collected at least every 5 seconds and continue for a period of 60 minutes after the test. A first-order lag (time constant) up to a maximum of 5 seconds may be applied to the measurements to provide "smoothing" and filter the effects of spurious data points.

2.8. The filtered readings from each sensor shall be below the targeted criteria of 3 ± 1.0 % for hydrogen or 2.25 ± 0.75 % for helium at all times throughout the 60 minutes post-crash test period.

3. Compliance test for single failure conditions

Either test procedure of paragraph 3.1. or paragraph 3.2. shall be executed:

3.1. Test procedure for vehicle equipped with hydrogen gas leakage detectors

3.1.1. Test condition

3.1.1.1. 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.

3.1.1.2. Test gas: Two mixtures of air and hydrogen gas: 2 ± 1.0 % concentration (or less) of hydrogen in the air to verify function of the warning, and 3 ± 1.0 % concentration (or less) of hydrogen in the air to verify function of the shut-down. The proper concentrations are selected based on the recommendation (or the detector specification) by the manufacturer.

3.1.2. Test method

3.1.2.1. 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.

3.1.2.2. 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.

3.2. Test procedure for integrity of enclosed spaces and detection systems.

3.2.1. Preparation:

The test is conducted without any influence of wind.

Special attention is paid to the test environment as during the test flammable mixtures of hydrogen and air may occur.

3.2.1.1. 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 shutoff 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.

3.2.1.2. 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 7.2.3.2. 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 7.2.3.1.

3.2.2. Procedure:

Vehicle doors, windows and other covers are closed.

The propulsion system is started, allowed to warm up to its normal operating temperature and left operating at idle for the test duration.

A leak is simulated using the remote controllable function.

The hydrogen concentration is measured continuously until the concentration does not rise for 3 minutes. When testing for compliance with paragraph 7.2.3.3. of this Regulation, the simulated leak is then increased using the remote controllable function until the main hydrogen shutoff 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.

When testing for compliance with paragraph 7.2.3.2. of this Regulation, the test is successfully completed if the hydrogen concentration in the passenger compartment does not exceed 1.0 %. When testing for compliance with paragraph 7.2.3.3. 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 7.2.3.3. of this Regulation; otherwise, the test is failed and the system is not qualified for vehicle service.

4. Compliance test for the vehicle exhaust system

4.1. The power system of the test vehicle (e.g. fuel cell stack or engine) is warmed up to its normal operating temperature.

4.2. The measuring device is warmed up before use to its normal operating temperature.

4.3. 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.

4.4. 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; and

(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.

4.5. The measurement device shall have a measurement response time of less than 300 milliseconds.

5. Compliance test for fuel line leakage

5.1. 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.

5.2. 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.

5.3. Hydrogen leak detection is performed primarily at joints.

5.4. 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.

5.5. 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 in order to check for bubbles caused by trace leaks.

6. Installation verification

The system is visually inspected for compliance.

7. Post-crash leak test for the liquefied hydrogen storage systems

Prior to the vehicle crash test, the following steps are taken to prepare the liquefied hydrogen storage system (LHSS):

(a) If the vehicle does not already have the following capabilities as part of the standard vehicle; the following shall be installed before the test:

- LHSS pressure sensor. The pressure sensor shall have a full scale of reading of at least 150 % of MAWP, an accuracy of at least 1 % of full scale, and capable of reading values of at least 10 kPa;
- LHSS temperature sensor. The temperature sensor shall be capable of measuring cryogenic temperatures expected before crash. The sensor is located on an outlet, as near as possible to the container;

(b) Fill and drain ports. The ability to add and remove both liquefied and gaseous contents of the LHSS before and after the crash test shall be provided;

(c) The LHSS is purged with at least 5 volumes of nitrogen gas;

(d) The LHSS is filled with nitrogen to the equivalence of the maximum fill level of hydrogen by weight;

(e) After fill, the (nitrogen) gas vent is to be closed, and the container allowed to equilibrate.

The leak-tightness of the LHSS is confirmed.

After the LHSS pressure and temperature sensors indicate that the system has cooled and equilibrated, the vehicle shall be crashed per state or regional regulation. Following the crash, there shall be no visible leak of cold nitrogen gas or liquid for a period of at least 1 hour after the crash. Additionally, the operability of the pressure controls or PRDs shall be proven to ensure that the LHSS is protected against burst after the crash. If the LHSS vacuum has not been compromised by the crash, nitrogen gas may be added to the LHSS via the fill / drain port until pressure controls and/or PRDs are activated. In the case of re-closing pressure controls or PRDs, activation and re-closing for at least 2 cycles shall be demonstrated. Exhaust from the venting of the pressure controls or the PRDs shall not be vented to the passenger or luggage, compartments during these post-crash tests.

Either test procedure referred to in paragraph 7.1. or the alternative test procedure in paragraph 7.2. (consisting of paragraphs 7.2.1. and 7.2.2.) may be chosen at the discretion of the manufacturer.

7.1. Post-crash leak test for the liquefied hydrogen storage systems

7.1.1. Following confirmation that the pressure control and/or safety relief valves are still functional, the leak tightness of the LHSS may be proven by detecting all possible leaking parts with a sniff sensor of a calibrated Helium leak test device used in sniff modus. The test can be performed as an alternative if the following pre-conditions are fulfilled:

(a) No possible leaking part shall be below the liquid nitrogen level as indicated on the storage container;

(b) All possible leaking parts are pressurized with helium gas when the LHSS is pressurized;

(c) Required covers and/or body panels and parts can be removed to gain access to all potential leak sites.

7.1.2. Prior to the test the manufacturer shall provide a list of all possible leaking parts of the LHSS. Possible leaking parts are:

(a) Any connectors between pipes and between pipes and the container;

(b) Any welding of pipes and components downstream the container;

(c) Valves;

(d) Flexible lines;

(e) Sensors.

7.1.3. Prior to the leak test overpressure in the LHSS should be released to atmospheric pressure and afterwards the LHSS should be pressurized with helium to at least the operating pressure but well below the normal pressure control setting (so the pressure regulators do not activate during the test period). The test is passed if the total leakage amount (i.e. the sum of all detected leakage points) is less than 216 Nml/hr.

7.2. Alternative post-crash tests for the liquefied hydrogen storage systems

Both tests of paragraphs 7.2.1. and 7.2.2. are conducted under the test procedure referred to in of paragraph 7.2.

7.2.1. Alternative post-crash leak test

7.2.1.1. Following confirmation that the pressure control and/or safety relief valves are still functional, the following test may be conducted to measure the post-crash leakage. The concentration test described in Annex 5, paragraph 1.2. shall be conducted in parallel for the 60-minute test period if the hydrogen concentration has not already been directly measured following the vehicle crash.

7.2.1.2. The container shall be vented to atmospheric pressure and the liquefied contents of the container shall be removed and the container shall be heated up to ambient temperature. The heat-up could be done, e.g. by purging the container sufficient times with warm nitrogen or increasing the vacuum pressure.

7.2.1.3. If the pressure control set point is less than 90 % of the MAWP, the pressure control shall be disabled so that it does not activate and vent gas during the leak test.

7.2.1.4. The container shall then be purged with helium by either:

(a) flowing at least 5 volumes through the container; or

(b) pressurizing and de-pressurizing the container the LHSS at least 5 times.

7.2.1.5. The LHSS shall then be filled with helium to 80 % of the MAWP of the container or to within 10 % of the primary relief valve setting, whichever results in the lower pressure, and held for a period of 60 minutes. The measured pressure loss over the 60-minute test period shall be less than or equal to the following criterion based on the liquid capacity of the LHSS:

(a) 0.20 MPa allowable loss for 100 l systems or less;

(b) 0.10 MPa allowable loss for systems greater than 100 l and less than or equal to 200 l; and

(c) 0.05 MPa allowable for systems greater than 200 l.

7.2.2. Post-crash enclosed spaces test

7.2.2.1. The measurements shall be recorded in the crash test that evaluates potential liquid hydrogen leakage in test procedure paragraph 7.2.1. if the LHSS contains hydrogen for the crash test or during the helium leak test in test procedure in paragraph 2 of this annex.

7.2.2.2. Select sensors to measure the build-up of hydrogen or helium (depending which gas is contained within the Liquefied Hydrogen Storage Systems (LHSS) for the crash test). Sensors may measure either measure the hydrogen/helium content of the atmosphere within the compartments or measure the reduction in oxygen (due to displacement of air by leaking hydrogen/helium).

7.2.2.3. The sensors shall be calibrated to traceable references, have an accuracy of 5 % of reading at the targeted criteria of 4 % hydrogen (for a test with liquefied hydrogen) or 0.8 % helium by volume in the air (for a test at room temperature with helium), and a full-scale measurement capability of at least 25 % above the target criteria. The sensor shall be capable of a 90 % response to a full-scale change in concentration within 10 seconds.

7.2.2.4. The installation in vehicles with LHSS shall meet the same requirements as for vehicles with compressed hydrogen storage systems in paragraph 2. Data from the sensors shall be collected at least every 5 seconds and continue for a period of 60 minutes after the vehicle comes to a rest if post-crash hydrogen is being measured or after the initiation of the helium leak test if helium build-up is being measured. Up to a 5 second rolling average may be applied to the measurements to provide "smoothing" and filter effects of spurious data paragraphs. The rolling average of each sensor shall be below the targeted criteria of 4 % hydrogen (for a test with liquefied hydrogen) or 0.8 % helium by volume in the air (for a test at room temperature with helium) at all times throughout the 60-minute post-crash test period.

Submitted by the TF on
UN-R 134 & OICA

Informal document **GRSP-77-xyz**
(77th GRSP, 5-9 May 2025,
agenda item 14)

Annex 6

Provisions for a label for liquefied hydrogen vehicles of categories M_2/N_2 and M_3/N_3.

(Paragraph 8. of this Regulation)

The label consists of a sticker which shall be weather resistant.

The centre zone indicates the first energy source.

The upper zone indicates the second energy source.

The left zone indicates the gas behaviour due to density.

The right zone indicates the state of aggregation of stored liquefied fuel.

Layout and symbols shall be in accordance with ISO 17840-4:2018.

The colour and dimensions of the sticker shall fulfil the following requirements:

Colours:

Background: Light-blue, RGB code 0, 176, 240

Border: white or white reflecting

Letters: white or white reflecting

Dimensions:

Sticker width: 110 – 150 mm

Sticker height: 80 – 110 mm"

Option 2

Proposal for a new Supplement to the 03 series of amendments to UN Regulation No. 134 (Hydrogen and fuel cell vehicles)

Submitted by the Kingdom of the Netherlands and the International Organization of Motor Vehicle Manufacturers (OICA)*

The text reproduced below was prepared by TF-R134, involving France, Japan, the Kingdom of the Netherlands, the European Commission, the European Association of Automotive Suppliers (CLEPA) and OICA, as well as related industry experts on transposing amendment 1 to UN Global Technical Regulation (GTR) No. 13, Phase 2 into a UN Regulation under the 1958 Agreement.

* In accordance with the programme of work of the Inland Transport Committee for 2025 as outlined in proposed programme budget for 2025 (A/79/6 (Sect. 20), table 20.6), the World Forum will develop, harmonize and update UN Regulations in order to enhance the performance of vehicles. The present document is submitted in conformity with that mandate.

I. Proposal

Amend table of contents, to read:

"Contents

Page

Insert new paragraphs 1.4 to 1.6, to read:

"**1.4.** **Part I - Liquefied hydrogen storage systems (LHSS) for hydrogen-fuelled vehicles on their safety-related performance.**

1.5. **Part II - Specific components for liquefied hydrogen storage systems (LHSS) for hydrogen-fuelled vehicles on their safety-related performance.**

1.6. **Part III - Hydrogen-fuelled vehicles of category M and N[2] incorporating liquefied hydrogen storage system (LHSS) on its safety-related performance.** "

Insert new paragraph 2.13, to read:

"**2.13.** **"*Liquefied Hydrogen Storage System (LHSS)*" means liquefied hydrogen storage container(s) PRDs, shut-off device, a boil-off system and the interconnection piping (if any) and fittings between the above components.**"

Renumber paragraphs 2.13 to 2.31 (former) to 2.14 to 2.32:

Amend paragraph 7.1.7., to read:

"7.1.7. Identification of hydrogen fuelled vehicles.

On vehicles of the categories M_2/N_2 and M_3/N_3, equipped with a compressed hydrogen system, labels shall be installed as specified in Annex 6 **– Part 1**.

…"

Insert new paragraphs 8 to 10.5, to read:

"8. Part IV – Specifications of the Liquefied Hydrogen Storage System (LHSS)

This part specifies the requirements for the liquefied hydrogen storage system.

The boundaries of the LHSS are defined by the interfaces which can isolate the stored liquefied (and/or gaseous) hydrogen from the remainder of the fuel system and the environment. All components located within this boundary are subject to the requirements defined in this paragraph. - Figure 1 shows a typical LHSS. The closure devices shall include the following functions, which may be combined:

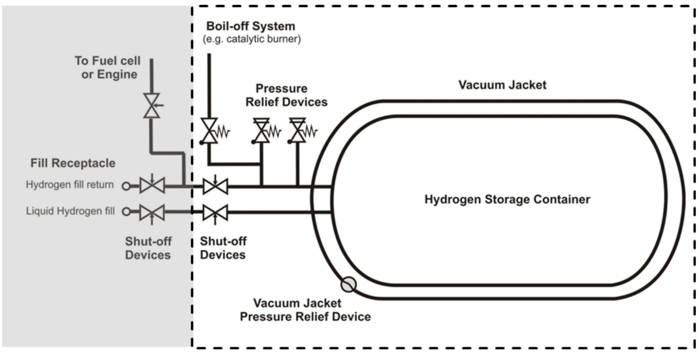
(a) Automatic shut-off device;

(b) Boil-off system;

(c) Pressure Relief Device (PRD).

Figure 2

Typical liquefied hydrogen storage system



The liquefied hydrogen storage system shall qualify for the performance test requirements specified in this paragraph. The manufacturer shall specify a Maximum Allowable Working Pressure (MAWP).

The test elements within these performance requirements are summarized in Table 1.

Table 2

Overview of performance requirements

Paragraph 8.1. Verification of baseline metrics **8.1.1. Proof pressure** **8.1.2. Baseline initial burst pressure, performed on the inner container** **8.1.3. Baseline Pressure cycle life**
Paragraph 8.2. Verification of expected on-road performance **8.2.1. Boil-off** **8.2.2. Leak** **8.2.3. Vacuum loss**
Paragraph 8.3. Verification for service-terminating conditions: Bonfire test
Paragraph 8.2.4. Requirements for pressure relief device and shut-off device

8.1. Verification of baseline metrics

8.1.1. Proof pressure

A system is pressurized to a pressure p_{test} ≥ 1.3 (MAWP ± 0.1 MPa) in accordance with the test procedure in Annex 10, paragraph 1.1. without visible deformation, degradation of container pressure, or detectable leakage.

8.1.2. Baseline initial burst pressure

The burst test is performed in accordance with the test procedure in Annex 10, paragraph 1.2. on one sample of the inner container that is not integrated in its outer jacket and not insulated.

The burst pressure shall be at least equal to the burst pressure used for the mechanical calculations. For steel containers that is either:

(a) Maximum Allowable Working Pressure (MAWP) (in MPa) plus 0.1 MPa multiplied by 3.25;

or

(b) Maximum Allowable Working Pressure (MAWP) (in MPa) plus 0.1 MPa multiplied by 1.5 and multiplied by Rm/Rp, where Rm is the minimum ultimate tensile strength of the container material and Rp (minimum yield strength) is 1.0 for austenitic steels and Rp is 0.2 for other steels.

8.1.3. Baseline pressure cycle life

When using metallic containers and/or metallic vacuum jackets, the manufacturer shall either provide a calculation in order to demonstrate that the container is designed according to current regional legislation or accepted standards (e.g. in US the ASME Boiler and Pressure Vessel Code, in Europe EN 1251-1:2000 and EN 1251-2:2000 and in all other countries an applicable regulation for the design of metallic pressure containers), or define and perform suitable tests (including Annex 10, paragraph 1.3.) that prove the same level of safety compared to a design supported by calculation according to accepted standards.

For non-metallic containers and/or vacuum jackets, in addition to the tests in Annex 10, paragraph 1.3., suitable tests shall be designed by the manufacturer to prove the same level of safety as a metallic container.

8.2. Verification for expected on-road performance

8.2.1. Boil-off

The boil-off test is performed on a liquefied hydrogen storage system equipped with all components as described in paragraph 8. (Figure 1). The test is performed on a system filled with liquid hydrogen in accordance with the test procedure in Annex 10, paragraph 2.1. and shall demonstrate that the boil-off system limits the pressure in the inner storage container to below the maximum allowable working pressure.

8.2.2. Leak

After the boil-off test in paragraph 2.1. of Annex 10, the system is kept at boil-off pressure and the total discharge rate due to leakage shall be measured in accordance with the test procedure in Annex 10, paragraph 2.2. The maximum allowable discharge from the hydrogen storage system is R*150 Nml/min where

R = $(V_{width}+1)*(V_{height}+0.5)*(V_{length}+1)/30.4$ **and** V_{width}, V_{height}, V_{length} **are the vehicle width, height, length (m), respectively.**

8.2.3. Vacuum loss

The vacuum loss test is performed on a liquefied hydrogen storage system equipped with all components as described in paragraph 8. (Figure 1). The test is performed on a system filled with liquid hydrogen in accordance with the test procedure in Annex 10, paragraph 2.3. and shall demonstrate that both primary and secondary pressure relief devices limit the pressure to the values specified in Annex 10, paragraph 2.3. if vacuum pressure is lost.

8.3. Verification of service-terminating conditions: Bonfire test

The function of the pressure relief devices and the absence of rupture under the following service terminating conditions shall be demonstrated in accordance with the test procedures provided in Annex 10, paragraph 3.

A hydrogen storage system is filled to half-full liquid level and exposed to fire in accordance with the test procedure of Annex 10, paragraph 3. The pressure relief device(s) shall release the contained gas in a controlled manner without rupture.

For steel containers, the test is successfully completed when the requirements on the pressure limits for the pressure relief devices as described in Annex 10, paragraph 3. are fulfilled. For other container materials, an equivalent level of safety shall be demonstrated.

8.4. 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, MAWP, fuel type (i.e. "LH_2" for liquid hydrogen).

9. Part V – Specifications of the specific components for liquefied hydrogen storage system (LHSS)

9.1. Pressure relief device qualification requirements

The pressure relief device shall meet the following performance qualification requirements:

(a) Pressure test (Annex 11, paragraph 1. test procedure);

(b) External leakage test (Annex 11, paragraph 2. test procedure);

(c) Operational test (Annex 11, paragraph 4. test procedure);

(d) Corrosion resistance test (Annex 11, paragraph 5. test procedure);

(e) Temperature cycle test (Annex 11, paragraph 8. test procedure).

9.2. Shut-off device qualification requirements

The shut-off device shall meet the following performance qualification requirements:

(a) Pressure test (Annex 11, paragraph 1. test procedure);

(b) External leakage Test (Annex 11, paragraph 2. test procedure);

(c) Endurance test (Annex 11, paragraph 3. test procedure);

(d) Corrosion resistance test (Annex 11, paragraph 5. test procedure);

(e) Resistance to dry-heat test (Annex 11, paragraph 6. test procedure);

(f) Ozone ageing test (Annex 11, paragraph 7. test procedure);

(g) Temperature cycle test (Annex 11, paragraph 8. test procedure);

(h) Flex line cycle test (Annex 11, paragraph 9. test procedure).

10. Part VI – Specifications of vehicle fuel system incorporating LHSS

This part specifies requirements for the integrity of the hydrogen fuel delivery system, which includes the liquefied hydrogen storage system, piping, joints, and components in which hydrogen is present. The fuelling receptacle label shall designate liquid hydrogen as the fuel type. Test procedures are given in Annex 12.

10.1. In-use fuel system integrity

10.1.1. Fuelling receptacle requirements

10.1.1.1. A label shall be affixed close to the fuelling receptacle; for instance, inside a refilling hatch, showing the following information: fuel type (e.g. "LH_2" for liquefied hydrogen), NWP, MFP, date of removal from service of containers.

10.1.1.2. 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.

10.1.1.3. 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.

10.1.1.4. If appropriate, the geometry of the fuelling receptacle of liquefied hydrogen gas vehicles may be at the manufacturer's discretion and in agreement with the technical service in absence of a standard.

10.2. In-use fuel system integrity

10.2.1. 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 over-pressure protection shall comply with the installation verification referred to in Annex 12, paragraph 6.

10.2.2. Hydrogen discharge systems

10.2.2.1. Pressure relief systems

Pressure relief devices (such as a burst disc) shall comply with the installation verification referred to in Annex 12, paragraph 6. and may be used outside the hydrogen storage system. The hydrogen gas discharge from other pressure relief devices shall not be directed:

(a) towards exposed electrical terminals, exposed electrical switches or other ignition sources;

(b) into or towards the vehicle passenger or luggage compartments;

(c) into or towards any vehicle wheel housing; and

(d) towards hydrogen gas containers.

10.2.2.2. Vehicle exhaust system

10.2.2.2.1. The vehicle exhaust system shall comply with the test for the vehicle exhaust system referred to in Annex 12, paragraph 4.

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

(a) Not exceed 4 % average by volume during any moving three-second time interval during normal operation including start-up and shutdown; and

(b) Not exceed 8 % at any time.

10.2.3. Protection against flammable conditions: single failure conditions

10.2.3.1. Hydrogen leakage and/or permeation from the hydrogen storage system shall not directly vent into the passenger, luggage, or cargo compartments, or to any enclosed or semi-enclosed spaces within the vehicle that contains unprotected ignition sources.

10.2.3.2. Any single failure downstream of the main hydrogen shut off valve shall not result in any level of a hydrogen concentration in anywhere in the passenger compartment according to test procedure referred to in Annex 12, paragraph 3.2.

10.2.3.3. If, during operation, a single failure results in a hydrogen concentration exceeding 3 % by volume in air in the enclosed or semi-enclosed spaces of the vehicle, then a warning shall be provided (paragraph 10.2.3.5.). If the hydrogen concentration exceeds 4 % by volume in the air in the enclosed or semi-enclosed spaces of the vehicle, the main shutoff valve shall be closed to isolate the storage system. (Annex 12, paragraph 3. test procedure).

10.2.3.4. 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 12, paragraph 5. test procedure).

10.2.3.5. 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;

(b) Yellow in colour if the detection system malfunctions (e.g. circuit disconnection, short-circuit, sensor fault). It shall be red in compliance with paragraph 10.2.3.3.

(c) When illuminated, shall be visible to the driver under both daylight and night time driving conditions; and

(d) Remains illuminated when 3 % concentration or detection system malfunction) exists and the master control is in the 'on' position or the propulsion system is otherwise activated.

10.2.3.6 Identification of hydrogen fuelled vehicles.

On vehicles of the categories M_2/N_2 and M_3/N_3, equipped with a liquefied hydrogen system, labels shall be installed as specified in Annex 6 – Part 2.

These labels shall be placed on the front of the vehicle and on the left side as well as on the right side of the vehicle; for the side in vicinity of a front door, if available. If there is no front door available, the label must be placed on the first third of the vehicle length. In addition, for vehicles of category M_2 and M_3, a label shall be fixed to the rear of the vehicle.

10.3. Post-crash fuel system integrity

The vehicle fuel system shall comply with the following requirements after the vehicle crash tests in accordance with the following UN Regulations by also applying the test procedures prescribed in Annex 12 to this Regulation.

(a) Frontal impact test procedures in accordance with either Regulation No. 12, or Regulation No. 94, Annex 3 and Regulation No. 137, Annex 3 only to the extent where the Regulations apply as prescribed in their scope; and

(b) Lateral impact test procedures in accordance with UN Regulation No. 95, Annex 4.

At the request of the manufacturer, for vehicles not in the scope of these UN Regulations and that are derived from M_1 or N_1 vehicle categories, they may be tested in accordance with the crash test procedures in these UN Regulations.

This requirement is deemed to be met if the vehicle equipped with LHSS is approved in accordance with UN Regulation No. 94 (05 series of amendments or later) or UN Regulation No. 137 (03 series of amendments or later) for frontal impact and UN Regulation No. 95 (06 series of amendments or later) for lateral impact, as applicable in the scope of aforementioned crash regulations.

Where one or more of these crash tests are not required, the LHSS, including the safety devices affixed to it shall be installed in such a way that the following accelerations can be absorbed without breaking of the fixation or loosening of the filled LHSS container(s):

Vehicle of categories M_1 and N_1:

(a) 20 g in forward and rearward direction of travel; and

(b) 8 g horizontally perpendicular to the direction of travel.

Vehicles of categories M_2 and N_2:

(a) 10 g in forward direction of travel; and

(b) 5 g horizontally perpendicular to the direction of travel.

Vehicles of categories M_3 and N_3:

(a) 6.6 g in the forward direction of travel; and

(b) 5 g horizontally perpendicular to the direction of travel.

Any substitute mass used shall be representative for a fully equipped and filled LHSS container/assembly.

10.3.1. Fuel leakage limit

The volumetric flow of hydrogen gas leakage shall not exceed an average of 118 NL per minute for 60 minutes after the crash as determined in accordance with Annex 12, paragraph 1.

10.3.2. Concentration limit in enclosed spaces

Hydrogen gas leakage shall not result in a hydrogen concentration in the air greater than 4 % by volume in the passenger and luggage compartments (Annex 12, paragraph 2. test procedures). The requirement is satisfied if it is confirmed that the shut-off valve of the storage system has closed within 5 seconds of the crash and no leakage from the storage system.

10.3.3. Container Displacement

The storage container(s) shall remain attached to the vehicle at a minimum of one attachment point.

10.4. Flammable materials used in the vehicle shall be protected from liquefied air that may condense on elements of the fuel system.

10.5. The insulation of the components shall prevent liquefaction of the air in contact with the outer surfaces, unless a system is provided for collecting and vaporizing the liquefied air. The materials of the components nearby shall be compatible with an atmosphere enriched with oxygen. "

Renumber paragraphs 8 to 13… (former) to 11 to 16…:

16. Transitional provisions

…[to be discussed]

Amend Annex 6, to read:

"**Annex 6 – Part 1**

Provisions for a label for compressed hydrogen vehicles of categories M_2/N_2 and M_3/N_3.

…"

Insert new Annex 6 – Part 2, to read:

"Annex 6 – Part 2

Provisions for a label for liquefied hydrogen vehicles of categories M_2/N_2 and M_3/N_3.

(Paragraph 7. of this Regulation)

The label consists of a sticker which shall be weather resistant.

The centre zone indicates the first energy source.

The upper zone indicates the second energy source.

The left zone indicates the gas behaviour due to density.

The right zone indicates the state of aggregation of stored liquefied fuel.

Layout and symbols shall be in accordance with ISO 17840-4:2018.

The colour and dimensions of the sticker shall fulfil the following requirements:

Colours:

Background : white

Border : light blue or light blue reflecting, RGB code 0, 176, 240

Letters and symbols : light blue or light blue reflecting, RGB code 0, 176, 240

Dimensions:

Sticker width: ≥ 110 mm

Sticker height: ≥ 80 mm"

Insert new Annexes 10 to 12, to read:

"Annex 10

Test procedures for LHSS design qualification

1. Verification tests for Baseline metrics

1.1. Proof pressure test

The inner container and the pipe work situated between the inner container and the outer jacket shall withstand an inner pressure test at room temperature according to the following requirements.

The test pressure p_{test} is defined by the manufacturer and shall fulfil the following requirements:

$p_{test} \geq 1.3$ (MAWP ± 0.1 MPa)

(a) For metallic containers, either p_{test} is equal to or greater than the maximum pressure of the inner container during fault management (as determined in Annex 10, paragraph 2.3.) or the manufacturer proves by calculation that at the maximum pressure of the inner container during fault management no yield occurs;

(b) For non-metallic containers, p_{test} is equal to or greater than the maximum pressure of the inner container during fault management (as determined in Annex 10, paragraph 2.3.).

The test is conducted according to the following procedure:

(a) The test is conducted on the inner storage container and the interconnecting pipes between inner storage container and vacuum jacket before the outer jacket is mounted;

(b) The test is either conducted hydraulically with water or a glycol/water mixture, or alternatively with gas. The container is pressurized to test pressure ptest at an even rate and kept at that pressure for at least 10 minutes;

(c) The test is done at ambient temperature. In the case of using gas to pressurize the container, the pressurization is done in a way that the container temperature stays at or around ambient temperature.

The test is passed successfully if, during the first 10 minutes after applying the proof pressure, no visible permanent deformation, no visible degradation in the container pressure and no visible leakage are detectable.

1.2. Baseline initial burst pressure

The test is conducted according to the following procedure:

(a) The test is conducted on the inner container at ambient temperature;

(b) The test is conducted hydraulically with water or a water/glycol mixture;

(c) The pressure is increased at a constant rate, not exceeding 0.5 MPa/min until burst or leakage of the container occurs;

(d) When MAWP is reached there is a wait period of at least ten minutes at constant pressure, during which time the deformation of the container can be checked;

(e) The pressure is recorded or written during the entire test.

For steel inner containers, the test is passed successfully if at least one of the two passing criteria described in paragraph 5.1.2. of this Regulation is fulfilled. For inner containers made out of an aluminium alloy or other material, a passing criterion shall be defined which guarantees at least the same level of safety compared to steel inner containers.

1.3. Baseline pressure cycle life

Containers and/or vacuum jackets are pressure cycled with a number of cycles at least three times the number of possible full pressure cycles (from the lowest to highest operating pressure) for an expected on-road performance. The number of pressure cycles is defined by the manufacturer under consideration of operating pressure range, size of the storage and, respectively, maximum number of refuellings and maximum number of pressure cycles under extreme usage and storage conditions. Pressure cycling is conducted between atmospheric pressure and MAWP at liquid nitrogen temperatures, e.g. by filling the container with liquid nitrogen to certain level and alternately pressurizing and depressurizing it with (pre-cooled) gaseous nitrogen or helium.

2. Verification for expected on-road performance

2.1. Boil-off test

The test is conducted according to the following procedure:

(a) For pre-conditioning, the container is fuelled with liquid hydrogen to the specified maximum filling level. Hydrogen is subsequently extracted until it meets half filling level, and the system is allowed to completely cool down for at least 24 hours and a maximum of 48 hours;

(b) The container is filled to the specified maximum filling level;

(c) The container is pressurized until boil-off pressure is reached;

(d) The test lasts for at least another 48 hours after boil-off started and is not terminated before the pressure stabilizes. Pressure stabilization has occurred when the average pressure does not increase over a two hour period.

The pressure of the inner container is recorded or written during the entire test. The test is passed successfully if the following requirements are fulfilled:

(a) The pressure stabilizes and stays below MAWP during the whole test;

(b) The pressure relief devices are not allowed to open during the whole test.

The pressure of the inner container shall be recorded or written during the entire test. The test is passed when the following requirements are fulfilled:

(a) The pressure shall stabilize and stay below MAWP during the whole test;

(b) The pressure relief devices are not allowed to open during the whole test.

2.2. Leak test

The test shall be conducted according to the procedure described in Annex 4, paragraph 2.

2.3. Vacuum loss test

The first part of the test is conducted according to the following procedure:

(a) The vacuum loss test is conducted with a completely cooled-down container (according to the procedure in Annex 10, paragraph 2.1.);

(b) The container is filled with liquid hydrogen to the specified maximum filling level;

(c) The vacuum enclosure is flooded with air at an even rate to atmospheric pressure;

(d) The test is terminated when the first pressure relief device does not open any more.

The pressure of the inner container and the vacuum jacket is recorded or written during the entire test. The opening pressure of the first safety device is recorded or written. The first part of test is passed if the following requirements are fulfilled:

(a) The first pressure relief device opens below or at MAWP and limit the pressure to not more than 110 per cent of the MAWP;

(b) The first pressure relief device does not open at pressure above MAWP;

(c) The secondary pressure relief device does not open during the entire test.

After passing the first part, the test shall be repeated subsequently to re-generation of the vacuum and cool-down of the container as described above.

(a) The vacuum is re-generated to a value specified by the manufacturer. The vacuum shall be maintained at least 24 hours. The vacuum pump may stay connected until the time directly before the start of the vacuum loss;

(b) The second part of the vacuum loss test is conducted with a completely cooled-down container (according to the procedure in Annex 10, paragraph 2.1.);

(c) The container is filled to the specified maximum filling level;

(d) The line downstream the first pressure relief device is blocked and the vacuum enclosure is flooded with air at an even rate to atmospheric pressure;

(e) The test is terminated when the second pressure relief device does not open any more.

The pressure of the inner container and the vacuum jacket is recorded or written during the entire test. For steel containers the second part of the test is passed if the secondary pressure relief device does not open below 110 per cent of the set pressure of the first pressure relief device and limits the pressure in the container to a maximum 136 per cent of the MAWP if a safety valve is used, or, 150 per cent of the MAWP if a burst disk is used as the secondary pressure relief device. For other container materials, an equivalent level of safety shall be demonstrated.

3. Verification test for service-terminating performance due to fire

The tested liquefied hydrogen storage system shall be representative of the design and the manufacturing of the type to be homologated. Its manufacturing shall be completely finished and it shall be mounted with all its equipment.

The first part of the test is conducted according to the following procedure:

(a) The bonfire test is conducted with a completely cooled-down container (according to the procedure in Annex 10, paragraph 2.1.);

(b) The container contained during the previous 24 hours a volume of liquid hydrogen at least equal to half of the water volume of the inner container;

(c) The container is filled with liquid hydrogen so that the quantity of liquid hydrogen measured by the mass measurement system is half of the maximum allowed quantity that may be contained in the inner container;

(d) A fire burns 0.1 m underneath the container. The length and the width of the fire exceed the plan dimensions of the container by 0.1 m. The temperature of the fire is at least 590 ºC. The fire shall continue to burn for the duration of the test;

(e) The pressure of the container at the beginning of the test is between 0 MPa and 0.01 MPa at the boiling point of hydrogen in the inner container;

(f) The test shall continue until the storage pressure decreases to or below the pressure at the beginning of the test, or alternatively in case the first PRD is a re-closing type, the test shall continue until the safety device has opened for a second time;

(g) The test conditions and the maximum pressure reached within the container during the test are recorded in a test certificate signed by the manufacturer and the technical service.

The test is passed if the following requirements are fulfilled:

(a) The secondary pressure relief device is not operated below 110 per cent of the set pressure of the primary pressure relief device;

(b) The container shall not burst and the pressure inside the inner container shall not exceed the permissible fault range of the inner container.

The permissible fault range for steel containers is as follows:

(a) If a safety valve is used as secondary pressure relief device, the pressure inside the container does not exceed 136 per cent of the MAWP of the inner container;

(b) If a burst disc is used outside the vacuum area as secondary pressure relief device, the pressure inside the container is limited to 150 per cent of the MAWP of the inner container;

(c) If a burst disc is used inside the vacuum area as secondary pressure relief device, the pressure inside the container is limited to 150 per cent of the MAWP ± 0.1 MPa of the inner container.

For other materials, an equivalent level of safety shall be demonstrated.

Annex 11

Test procedures for specific component for LHSS

The test procedures for pressure relief devices (paragraph 9.1. of this Regulation) and shut-off valves (paragraph 9.2. of this Regulation) are described below:

Testing shall be performed with hydrogen gas having gas quality compliant with ISO 14687:2025/SAE J2719_202003. All tests shall be performed at ambient temperature 20(±5) °C unless otherwise specified.

1. Pressure test

A hydrogen containing component shall withstand without any visible evidence of leak or deformation a test pressure of 150 per cent MAWP with the outlets of the high-pressure part plugged. The pressure shall subsequently be increased from 150 per cent to 300 per cent MAWP. The component shall not show any visible evidence of rupture or cracks.

The pressure supply system shall be equipped with a positive shut-off valve and a pressure gauge having a pressure range of not less than 150 per cent and no more than 200 per cent of the test pressure; the accuracy of the gauge shall be 1 per cent of the pressure range.

For components requiring a leakage test, this test shall be performed prior to the pressure test.

2. External leakage test

A component shall be free from leakage through stem or body seals or other joints and shall not show evidence of porosity in casting when tested as described in Annex 11, paragraph 3.3. at any gas pressure between zero and its MAWP.

The test shall be performed on the same equipment at the following conditions:

(a) At ambient temperature;

(b) At the minimum operating temperature or at liquid nitrogen temperature after sufficient conditioning time at this temperature to ensure thermal stability;

(c) At the maximum operating temperature after sufficient conditioning time at this temperature to ensure thermal stability.

During this test, the equipment under test shall be connected to a source of gas pressure. A positive shut-off valve and a pressure gauge having a pressure range of not less than 150 per cent and not more than 200 per cent of the test pressure shall be installed in the pressure supply piping; the accuracy of the gauge shall be 1 per cent of the pressure range. The pressure gauge shall be installed between the positive shut-off valve and the sample under test.

Throughout the test, the sample shall be tested for leakage, with a surface-active agent without formation of bubbles or measured with a leakage rate less than 216 Nml/hr.

3. Endurance test

3.1. A component shall be capable of conforming to the applicable leakage test requirements of Annex 11, paragraphs 2. and 9., after being subjected to 20,000 operation cycles.

3.2. The appropriate tests for external leakage and seat leakage, as described in Annex 11, paragraphs 2. and 9. shall be carried out immediately following the endurance test.

3.3. The shut-off valve shall be securely connected to a pressurized source of dry air or nitrogen and subjected to 20,000 operation cycles. A cycle shall consist of one opening and one closing of the component within a period of not less than 10 ± 2 seconds.

3.4. The component shall be operated through 96 per cent of the number of specified cycles at ambient temperature and at the MAWP of the component. During the off cycle the downstream pressure of the test fixture shall be allowed to decay to 50 per cent of the MAWP of the component.

3.5. The component shall be operated through 2 per cent of the total cycles at the maximum material temperature (-40 °C to +85 °C) after sufficient conditioning time at this temperature to ensure thermal stability and at MAWP. The component shall comply with Annex 11, paragraphs 2. and 9. at the appropriate maximum material temperature (-40 °C to +85 °C) at the completion of the high temperature cycles.

3.6. The component shall be operated through 2 per cent of the total cycles at the minimum material temperature (-40 °C to +85 °C) but not less than the temperature of liquid nitrogen after sufficient conditioning time at this temperature to ensure thermal stability and at the MAWP of the component. The component shall comply with Annex 11, paragraphs 2. and 9. at the appropriate minimum material temperature (-40 °C to +85 °C) at the completion of the low temperature cycles.

4. Operational test

The operational test shall be carried out in accordance with EN 13648-1:2009 or EN 13648-2:2002. The specific requirements of the standard are applicable.

5. Corrosion resistance test

Metallic hydrogen components shall comply with the leakage tests referred to in Annex 11, paragraphs 2. and 9. after being submitted to 144 hours salt spray test according to ISO 9227:2022 with all connections closed.

A copper or brass hydrogen containing component shall comply with the leakage tests referred to in Annex 11, paragraphs 2. and 9. and after being submitted to 24 hours immersion in ammonia according to ISO 6957:1988 with all connections closed.

6. Resistance to dry-heat test

The test shall be carried out in compliance with ISO 188:2023. The test piece shall be exposed to air at a temperature equal to the maximum operating temperature for 168 hours. The change in tensile strength shall not exceed ±25 per cent. The change in ultimate elongation shall not exceed the following values:

- **maximum increase 10 per cent;**
- **maximum decrease 30 per cent.**

7. Ozone ageing Test

The test shall be in compliance with ISO 1431-1:2024. The test piece, which shall be stressed to 20 per cent elongation, shall be exposed to air at +40 °C with an ozone concentration of 50 parts per hundred million during 120 hours.

No cracking of the test piece is allowed.

8. Temperature cycle test

A non-metallic part containing hydrogen shall comply with the leakage tests referred to in Annex 11, paragraphs 2. and 9. after having been submitted to a 96-hour temperature cycle from the minimum operating temperature up to the maximum operating temperature with a cycle time of 120 minutes, under MAWP.

9. Flex line cycle test

Any flexible fuel line shall be capable of conforming to the applicable leakage test requirements referred to in Annex 11, paragraph 2., after being subjected to 6,000 pressure cycles.

The pressure shall change from atmospheric pressure to the MAWP of the container within less than five seconds, and after a time of at least five seconds, shall decrease to atmospheric pressure within less than five seconds.

The appropriate test for external leakage, as referred to in Annex 11, paragraph 2., shall be carried out immediately following the endurance test.

Annex 12

Test procedures for a vehicle fuel system incorporating LHSS

The test procedures for vehicle fuel systems incorporating LHSS according to paragraphs 1., 2. and 7. of this annex apply only to vehicles of categories M1 and N1 that are subjected to one or more crash tests.

1. Post-crash liquefied hydrogen storage system leak test

Prior to conducting the crash test, instrumentation is installed in the hydrogen storage system to perform the required pressure and temperature measurements if the standard vehicle does not already have instrumentation with the required accuracy.

The storage system is then purged, if necessary, following manufacturer directions to remove impurities from the container before filling the storage system with compressed hydrogen or helium gas. Since the storage system pressure varies with temperature, the targeted fill pressure is a function of the temperature. The target pressure shall be determined from the following equation:

$$P_{target} = NWP \times (273 + To) / 288$$

where NWP is the nominal working pressure (MPa), To is the ambient temperature to which the storage system is expected to settle, and P_{target} is the targeted fill pressure after the temperature settles.

The container is filled to a minimum of 95 % of the targeted fill pressure and allowed to settle (stabilize) prior to conducting the crash test.

The main stop valve and shut-off valves for hydrogen gas, located in the downstream hydrogen gas piping, are kept open immediately prior to the impact.

1.1. Post-crash leak test - compressed hydrogen storage system filled with compressed hydrogen

The hydrogen gas pressure, P0 (MPa), and temperature, T0 (°C), is measured immediately before the impact and then at a time interval, Δt (min), after the impact. The time interval, Δt, starts when the vehicle comes to rest after the impact and continues for at least 60 minutes. The time interval, Δt, is increased, if necessary, in order to accommodate measurement accuracy for a storage system with a large volume operating up to 70 MPa; in that case, Δt can be calculated from the following equation:

$$\Delta t = V_{CHSS} \times NWP / 1\,000 \times ((-0.027 \times NWP + 4) \times Rs - 0.21) - 1.7 \times Rs$$

where Rs = Ps / NWP, Ps is the pressure range of the pressure sensor (MPa), NWP is the Nominal Working Pressure (MPa), V_{CHSS} is the volume of the compressed hydrogen storage system (L), and Δt is the time interval (min). If the calculated value of Δt is less than 60 minutes, Δt is set to 60 minutes.

The initial mass of hydrogen in the storage system can be calculated as follows:

$$P_o' = P_o \times 288 / (273 + T_0)$$

$$P_o' = -0.0027 \times (P_0')^2 + 0.75 \times P_0' + 0.5789$$

$$M_o = \rho_o' \times V_{CHSS}$$

Correspondingly, the final mass of hydrogen in the storage system, M_f, at the end of the time interval, Δt, can be calculated as follows:

$$P_f' = P_f \times 288 / (273 + T_f)$$

$$\rho_f' = -0.0027 \times (P_f')^2 + 0.75 \times P_f' + 0.5789$$

$$M_f = \rho_f' \times V_{CHSS}$$

where P_f is the measured final pressure (MPa) at the end of the time interval, and T_f is the measured final temperature (°C).

The average hydrogen flow rate over the time interval (that shall be less than the criteria in paragraph 7.3.1.) is therefore:

$$V_{H2} = (M_f - M_o) / \Delta t \times 22.41 / 2.016 \times (P_{target} / P_o)$$

where V_{H2} is the average volumetric flow rate (NL/min) over the time interval and the term (P_{target} /P_o) is used to compensate for differences between the measured initial pressure, P_o, and the targeted fill pressure P_{target}.

1.2. Post-crash leak test - Compressed hydrogen storage system filled with compressed helium

The helium gas pressure, P_0 (MPa), and temperature T_0 (°C), are measured immediately before the impact and then at a predetermined time interval after the impact. The time interval, Δt, starts when the vehicle comes to rest after the impact and continues for at least 60 minutes.

The time interval, Δt, shall be increased, if necessary, in order to accommodate measurement accuracy for a storage system with a large volume operating up to 70MPa; in that case, Δt can be calculated from the following equation:

$$\Delta t = V_{CHSS} \times NWP /1\,000 \times ((-\,0.028 \times NWP + 5.5) \text{ x } R_s - 0.3) - 2.6 \times R_s$$

where $R_s = P_s / NWP$, P_s is the pressure range of the pressure sensor (MPa), NWP is the Nominal Working Pressure (MPa), V_{CHSS} is the volume of the compressed hydrogen storage system (L), and Δt is the time interval (min). If the value of Δt is less than 60 minutes, Δt is set to 60 minutes.

The initial mass of hydrogen in the storage system is calculated as follows:

$$P_o' = P_o \times 288 / (273 + T_0)$$

$$\rho_o' = -\,0.0043 \times (P_0')^2 + 1.53 \times P_0' + 1.49$$

$$M_o = \rho_o' \times V_{CHSS}$$

The final mass of hydrogen in the storage system at the end of the time interval, Δt, is calculated as follows:

$$P_f' = P_f \times 288 / (273 + T_f)$$

$$\rho_f' = -\,0.0043 \times (P_f')^2 + 1.53 \times P_f' + 1.49$$

$$M_f = \rho_f' \times V_{CHSS}$$

where P_f is the measured final pressure (MPa) at the end of the time interval, and T_f is the measured final temperature (°C).

The average helium flow rate over the time interval is therefore

$$V_{He} = (M_f - M_o) / \Delta t \times 22.41 / 4.003 \times (P_o / P_{target})$$

where V_{He} is the average volumetric flow rate (NL/min) over the time interval and the term P_o / P_{target} is used to compensate for differences between the measured initial pressure (P_o) and the targeted fill pressure (P_{target}).

Conversion of the average volumetric flow of helium to the average hydrogen flow is done with the following expression:

$$V_{H2} = V_{He} / 0.75$$

where V_{H2} is the corresponding average volumetric flow of hydrogen (that shall be less than the criteria in paragraph 7.3.1. of this Regulation to pass).

2. Post-crash concentration test for enclosed spaces

2.1. The measurements are recorded in the crash test that evaluates potential hydrogen (or helium) leakage as determined in accordance with paragraph 1.

2.2. Sensors are selected to measure either the build-up of the hydrogen or helium gas or the reduction in oxygen (due to displacement of air by leaking hydrogen/helium).

2.3. Sensors are calibrated to traceable references to ensure an accuracy of ±5 % at the targeted criteria of 4 % hydrogen or 3 % helium by volume in air, and a full-scale measurement capability of at least 25 % above the

target criteria. The sensor shall be capable of a 90 % response to a full-scale change in concentration within 10 seconds.

2.4. Prior to the crash impact, the sensors are located in the passenger and luggage compartments of the vehicle as follows:

(a) At a distance within 250 mm of the headliner above the driver's seat or near the top centre the passenger compartment;

(b) At a distance within 250 mm of the floor in front of the rear (or rear most) seat in the passenger compartment;

(c) At a distance within 100 mm of the top of luggage compartments within the vehicle that are not directly affected by the particular crash impact to be conducted.

2.5. The sensors are securely mounted on the vehicle structure or seats and protected for the planned crash test from debris, air bag exhaust gas and projectiles. The measurements following the crash are recorded by instruments located within the vehicle or by remote transmission.

2.6. The vehicle may be located either outdoors in an area protected from the wind and possible solar effects or indoors in a space that is large enough or ventilated to prevent the build-up of hydrogen to more than 10 % of the targeted criteria in the passenger, luggage, and cargo compartments.

2.7. Post-crash data collection in enclosed spaces commences when the vehicle comes to a rest. Data from the sensors are collected at least every 5 seconds and continue for a period of 60 minutes after the test. A first-order lag (time constant) up to a maximum of 5 seconds may be applied to the measurements to provide "smoothing" and filter the effects of spurious data points.

2.8. The filtered readings from each sensor shall be below the targeted criteria of 3 ± 1.0 % for hydrogen or 2.25 ± 0.75 % for helium at all times throughout the 60 minutes post-crash test period.

3. Compliance test for single failure conditions

Either test procedure of paragraph 3.1. or paragraph 3.2. shall be executed:

3.1. Test procedure for vehicle equipped with hydrogen gas leakage detectors

3.1.1. Test condition

3.1.1.1. 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.

3.1.1.2. Test gas: Two mixtures of air and hydrogen gas: 2 ± 1.0 % concentration (or less) of hydrogen in the air to verify function of the warning, and 3 ± 1.0 % concentration (or less) of hydrogen in the air to verify function of the shut-down. The proper concentrations are selected based on the recommendation (or the detector specification) by the manufacturer.

3.1.2. Test method

3.1.2.1. 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.

3.1.2.2. 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.

3.2. Test procedure for integrity of enclosed spaces and detection systems.

3.2.1. Preparation:

The test is conducted without any influence of wind.

Special attention is paid to the test environment as during the test flammable mixtures of hydrogen and air may occur.

3.2.1.1. 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 shutoff 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.

3.2.1.2. 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 10.2.3.2. 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 10.2.3.1.

3.2.2. Procedure:

Vehicle doors, windows and other covers are closed.

The propulsion system is started, allowed to warm up to its normal operating temperature and left operating at idle for the test duration.

A leak is simulated using the remote controllable function.

The hydrogen concentration is measured continuously until the concentration does not rise for 3 minutes. When testing for compliance with paragraph 10.2.3.3. of this Regulation, the simulated leak is then increased using the remote controllable function until the main hydrogen shutoff 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.

When testing for compliance with paragraph 10.2.3.2. of this Regulation, the test is successfully completed if the hydrogen concentration in the passenger compartment does not exceed 1.0 %. When testing for compliance with paragraph 10.2.3.3. 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 10.2.3.3. of this Regulation; otherwise, the test is failed and the system is not qualified for vehicle service.

4. Compliance test for the vehicle exhaust system

4.1. The power system of the test vehicle (e.g. fuel cell stack or engine) is warmed up to its normal operating temperature.

4.2. The measuring device is warmed up before use to its normal operating temperature.

4.3. 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.

4.4. 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; and

(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.

4.5. The measurement device shall have a measurement response time of less than 300 milliseconds.

5. Compliance test for fuel line leakage

5.1. 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.

5.2. 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.

5.3. Hydrogen leak detection is performed primarily at joints.

5.4. 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.

5.5. 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 in order to check for bubbles caused by trace leaks.

6. Installation verification

The system is visually inspected for compliance.

7. Post-crash leak test for the liquefied hydrogen storage systems

Prior to the vehicle crash test, the following steps are taken to prepare the liquefied hydrogen storage system (LHSS):

(a) If the vehicle does not already have the following capabilities as part of the standard vehicle; the following shall be installed before the test:

- **LHSS pressure sensor. The pressure sensor shall have a full scale of reading of at least 150 % of MAWP, an accuracy of at least 1 % of full scale, and capable of reading values of at least 10 kPa;**
- **LHSS temperature sensor. The temperature sensor shall be capable of measuring cryogenic temperatures expected before crash. The sensor is located on an outlet, as near as possible to the container;**

(b) Fill and drain ports. The ability to add and remove both liquefied and gaseous contents of the LHSS before and after the crash test shall be provided;

(c) The LHSS is purged with at least 5 volumes of nitrogen gas;

(d) The LHSS is filled with nitrogen to the equivalence of the maximum fill level of hydrogen by weight;

(e) After fill, the (nitrogen) gas vent is to be closed, and the container allowed to equilibrate.

The leak-tightness of the LHSS is confirmed.

After the LHSS pressure and temperature sensors indicate that the system has cooled and equilibrated, the vehicle shall be crashed per state or regional regulation. Following the crash, there shall be no visible leak of cold nitrogen gas or liquid for a period of at least 1 hour after the crash. Additionally, the operability of the pressure controls or PRDs shall be proven to ensure that the LHSS is protected against burst after the crash. If the LHSS vacuum has not been compromised by the crash, nitrogen gas may be added to the LHSS via the fill / drain port until pressure controls and/or PRDs are activated. In the case of re-closing pressure controls or PRDs, activation and re-closing for at least 2 cycles shall be demonstrated.

Exhaust from the venting of the pressure controls or the PRDs shall not be vented to the passenger or luggage, compartments during these post-crash tests.

Either test procedure referred to in paragraph 7.1. or the alternative test procedure in paragraph 7.2. (consisting of paragraphs 7.2.1. and 7.2.2.) may be chosen at the discretion of the manufacturer.

7.1. Post-crash leak test for the liquefied hydrogen storage systems

7.1.1. Following confirmation that the pressure control and/or safety relief valves are still functional, the leak tightness of the LHSS may be proven by detecting all possible leaking parts with a sniff sensor of a calibrated Helium leak test device used in sniff modus. The test can be performed as an alternative if the following pre-conditions are fulfilled:

(a) No possible leaking part shall be below the liquid nitrogen level as indicated on the storage container;

(b) All possible leaking parts are pressurized with helium gas when the LHSS is pressurized;

(c) Required covers and/or body panels and parts can be removed to gain access to all potential leak sites.

7.1.2. Prior to the test the manufacturer shall provide a list of all possible leaking parts of the LHSS. Possible leaking parts are:

(a) Any connectors between pipes and between pipes and the container;

(b) Any welding of pipes and components downstream the container;

(c) Valves;

(d) Flexible lines;

(e) Sensors.

7.1.3. Prior to the leak test overpressure in the LHSS should be released to atmospheric pressure and afterwards the LHSS should be pressurized with helium to at least the operating pressure but well below the normal pressure control setting (so the pressure regulators do not activate during the test period). The test is passed if the total leakage amount (i.e. the sum of all detected leakage points) is less than 216 Nml/hr.

7.2. Alternative post-crash tests for the liquefied hydrogen storage systems

Both tests of paragraphs 7.2.1. and 7.2.2. are conducted under the test procedure referred to in of paragraph 7.2.

7.2.1. Alternative post-crash leak test

7.2.1.1. Following confirmation that the pressure control and/or safety relief valves are still functional, the following test may be conducted to measure

the post-crash leakage. The concentration test described in Annex 12, paragraph 1.2. shall be conducted in parallel for the 60-minute test period if the hydrogen concentration has not already been directly measured following the vehicle crash.

7.2.1.2. The container shall be vented to atmospheric pressure and the liquefied contents of the container shall be removed and the container shall be heated up to ambient temperature. The heat-up could be done, e.g. by purging the container sufficient times with warm nitrogen or increasing the vacuum pressure.

7.2.1.3. If the pressure control set point is less than 90 % of the MAWP, the pressure control shall be disabled so that it does not activate and vent gas during the leak test.

7.2.1.4. The container shall then be purged with helium by either:

(a) flowing at least 5 volumes through the container; or

(b) pressurizing and de-pressurizing the container the LHSS at least 5 times.

7.2.1.5. The LHSS shall then be filled with helium to 80 % of the MAWP of the container or to within 10 % of the primary relief valve setting, whichever results in the lower pressure, and held for a period of 60 minutes. The measured pressure loss over the 60-minute test period shall be less than or equal to the following criterion based on the liquid capacity of the LHSS:

(a) 0.20 MPa allowable loss for 100 l systems or less;

(b) 0.10 MPa allowable loss for systems greater than 100 l and less than or equal to 200 l; and

(c) 0.05 MPa allowable for systems greater than 200 l.

7.2.2. Post-crash enclosed spaces test

7.2.2.1. The measurements shall be recorded in the crash test that evaluates potential liquid hydrogen leakage in test procedure paragraph 7.2.1. if the LHSS contains hydrogen for the crash test or during the helium leak test in test procedure in paragraph 2 of this annex.

7.2.2.2. Select sensors to measure the build-up of hydrogen or helium (depending which gas is contained within the Liquefied Hydrogen Storage Systems (LHSS) for the crash test). Sensors may measure either measure the hydrogen/helium content of the atmosphere within the compartments or measure the reduction in oxygen (due to displacement of air by leaking hydrogen/helium).

7.2.2.3. The sensors shall be calibrated to traceable references, have an accuracy of 5 % of reading at the targeted criteria of 4 % hydrogen (for a test with liquefied hydrogen) or 0.8 % helium by volume in the air (for a test at room temperature with helium), and a full-scale measurement capability

of at least 25 % above the target criteria. The sensor shall be capable of a 90 % response to a full-scale change in concentration within 10 seconds.

7.2.2.4. The installation in vehicles with LHSS shall meet the same requirements as for vehicles with compressed hydrogen storage systems in paragraph 2. Data from the sensors shall be collected at least every 5 seconds and continue for a period of 60 minutes after the vehicle comes to a rest if post-crash hydrogen is being measured or after the initiation of the helium leak test if helium build-up is being measured. Up to a 5 second rolling average may be applied to the measurements to provide "smoothing" and filter effects of spurious data paragraphs. The rolling average of each sensor shall be below the targeted criteria of 4 % hydrogen (for a test with liquefied hydrogen) or 0.8 % helium by volume in the air (for a test at room temperature with helium) at all times throughout the 60-minute post-crash test period. "

Proposal for the 04 series of amendments to UN Regulation No. 134 (Hydrogen and fuel cell vehicles)

Submitted by the experts from the International Organization of Motor Vehicle Manufacturers (OICA) and the Task Force amending UN Regulation No. 134 (TF-R134)*

The text reproduced below was prepared by TF-R134, involving France, Japan, the Kingdom of the Netherlands, the European Commission, the European Association of Automotive Suppliers (CLEPA) and OICA, as well as related industry experts on transposing amendment 1 to UN Global Technical Regulation (GTR) No. 13, Phase 2 into a UN Regulation under the 1958 Agreement.

* In accordance with the programme of work of the Inland Transport Committee for 2025 as outlined in proposed programme budget for 2025 (A/79/6 (Sect. 20), table 20.6), the World Forum will develop, harmonize and update UN Regulations in order to enhance the performance of vehicles. The present document is submitted in conformity with that mandate.

I. Proposal

Amend table of contents, to read:

"Contents

Page

Insert new paragraphs 1.4 to 1.6, to read:

"**1.4.** **Part I - Liquefied hydrogen storage systems (LHSS) for hydrogen-fuelled vehicles on their safety-related performance.**

1.5. **Part II - Specific components for liquefied hydrogen storage systems (LHSS) for hydrogen-fuelled vehicles on their safety-related performance.**

1.6. **Part III - Hydrogen-fuelled vehicles of category M and N[2] incorporating liquefied hydrogen storage system (LHSS) on its safety-related performance.** "

Insert new paragraph 2.13, to read:

"**2.13.** **"*Liquefied Hydrogen Storage System (LHSS)*" means liquefied hydrogen storage container(s) PRDs, shut-off device, a boil-off system and the interconnection piping (if any) and fittings between the above components.**"

Renumber paragraphs 2.13 to 2.31 (former) to 2.14 to 2.32:

Amend paragraph 7.1.7., to read:

"7.1.7. Identification of hydrogen fuelled vehicles.

On vehicles of the categories M_2/N_2 and M_3/N_3, equipped with a compressed hydrogen system, labels shall be installed as specified in Annex 6 **– Part 1**.

…"

Insert new paragraphs 8 to 10.5, to read:

"8. Part IV – Specifications of the Liquefied Hydrogen Storage System (LHSS)

This part specifies the requirements for the liquefied hydrogen storage system.

The boundaries of the LHSS are defined by the interfaces which can isolate the stored liquefied (and/or gaseous) hydrogen from the remainder of the fuel system and the environment. All components located within this boundary are subject to the requirements defined in this paragraph. - Figure 1 shows a typical LHSS. The closure devices shall include the following functions, which may be combined:

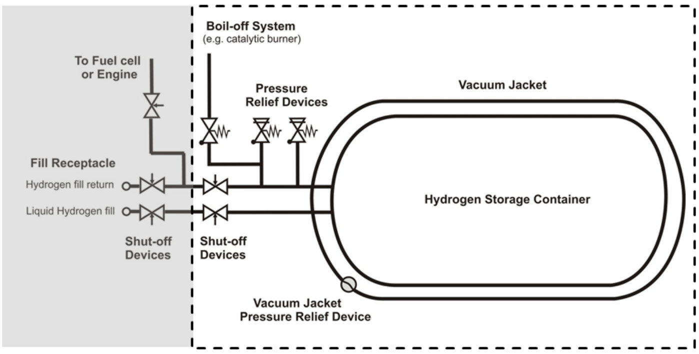
(a) **Automatic shut-off device;**

(b) **Boil-off system;**

(c) **Pressure Relief Device (PRD).**

Figure 2

Typical liquefied hydrogen storage system



The liquefied hydrogen storage system shall qualify for the performance test requirements specified in this paragraph. The manufacturer shall specify a Maximum Allowable Working Pressure (MAWP).

The test elements within these performance requirements are summarized in Table 1.

Table 2

Overview of performance requirements

Paragraph 8.1. Verification of baseline metrics **8.1.1. Proof pressure** **8.1.2. Baseline initial burst pressure, performed on the inner container** **8.1.3. Baseline Pressure cycle life**
Paragraph 8.2. Verification of expected on-road performance **8.2.1. Boil-off** **8.2.2. Leak** **8.2.3. Vacuum loss**
Paragraph 8.3. Verification for service-terminating conditions: Bonfire test
Paragraph 8.2.4. Requirements for pressure relief device and shut-off device

8.1. Verification of baseline metrics

8.1.1. Proof pressure

A system is pressurized to a pressure $p_{test} \geq 1.3$ (MAWP ± 0.1 MPa) in accordance with the test procedure in Annex 10, paragraph 1.1. without visible deformation, degradation of container pressure, or detectable leakage.

8.1.2. Baseline initial burst pressure

The burst test is performed in accordance with the test procedure in Annex 10, paragraph 1.2. on one sample of the inner container that is not integrated in its outer jacket and not insulated.

The burst pressure shall be at least equal to the burst pressure used for the mechanical calculations. For steel containers that is either:

(a) Maximum Allowable Working Pressure (MAWP) (in MPa) plus 0.1 MPa multiplied by 3.25;

or

(b) Maximum Allowable Working Pressure (MAWP) (in MPa) plus 0.1 MPa multiplied by 1.5 and multiplied by Rm/Rp, where Rm is the minimum ultimate tensile strength of the container material and Rp (minimum yield strength) is 1.0 for austenitic steels and Rp is 0.2 for other steels.

8.1.3. Baseline pressure cycle life

When using metallic containers and/or metallic vacuum jackets, the manufacturer shall either provide a calculation in order to demonstrate that the container is designed according to current regional legislation or accepted standards (e.g. in US the ASME Boiler and Pressure Vessel Code, in Europe EN 1251-1:2000 and EN 1251-2:2000 and in all other countries an applicable regulation for the design of metallic pressure containers), or define and perform suitable tests (including Annex 10, paragraph 1.3.) that prove the same level of safety compared to a design supported by calculation according to accepted standards.

For non-metallic containers and/or vacuum jackets, in addition to the tests in Annex 10, paragraph 1.3., suitable tests shall be designed by the manufacturer to prove the same level of safety as a metallic container.

8.2. Verification for expected on-road performance

8.2.1. Boil-off

The boil-off test is performed on a liquefied hydrogen storage system equipped with all components as described in paragraph 8. (Figure 1). The test is performed on a system filled with liquid hydrogen in accordance with the test procedure in Annex 10, paragraph 2.1. and shall demonstrate that the boil-off system limits the pressure in the inner storage container to below the maximum allowable working pressure.

8.2.2. Leak

After the boil-off test in paragraph 2.1. of Annex 10, the system is kept at boil-off pressure and the total discharge rate due to leakage shall be measured in accordance with the test procedure in Annex 10, paragraph 2.2. The maximum allowable discharge from the hydrogen storage system is R*150 Nml/min where

R = $(V_{width}+1)*(V_{height}+0.5)*(V_{length}+1)/30.4$ **and** V_{width}, V_{height}, V_{length} **are the vehicle width, height, length (m), respectively.**

8.2.3. Vacuum loss

The vacuum loss test is performed on a liquefied hydrogen storage system equipped with all components as described in paragraph 8. (Figure 1). The test is performed on a system filled with liquid hydrogen in accordance with the test procedure in Annex 10, paragraph 2.3. and shall demonstrate that both primary and secondary pressure relief devices limit the pressure to the values specified in Annex 10, paragraph 2.3. if vacuum pressure is lost.

8.3. Verification of service-terminating conditions: Bonfire test

The function of the pressure relief devices and the absence of rupture under the following service terminating conditions shall be demonstrated in accordance with the test procedures provided in Annex 10, paragraph 3.

A hydrogen storage system is filled to half-full liquid level and exposed to fire in accordance with the test procedure of Annex 10, paragraph 3. The pressure relief device(s) shall release the contained gas in a controlled manner without rupture.

For steel containers, the test is successfully completed when the requirements on the pressure limits for the pressure relief devices as described in Annex 10, paragraph 3. are fulfilled. For other container materials, an equivalent level of safety shall be demonstrated.

8.4. 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, MAWP, fuel type (i.e. "LH_2" for liquid hydrogen).

9. Part V – Specifications of the specific components for liquefied hydrogen storage system (LHSS)

9.1. Pressure relief device qualification requirements

The pressure relief device shall meet the following performance qualification requirements:

(a) Pressure test (Annex 11, paragraph 1. test procedure);

(b) External leakage test (Annex 11, paragraph 2. test procedure);

(c) Operational test (Annex 11, paragraph 4. test procedure);

(d) Corrosion resistance test (Annex 11, paragraph 5. test procedure);

(e) Temperature cycle test (Annex 11, paragraph 8. test procedure).

9.2. Shut-off device qualification requirements

The shut-off device shall meet the following performance qualification requirements:

(a) Pressure test (Annex 11, paragraph 1. test procedure);

(b) External leakage Test (Annex 11, paragraph 2. test procedure);

(c) Endurance test (Annex 11, paragraph 3. test procedure);

(d) Corrosion resistance test (Annex 11, paragraph 5. test procedure);

(e) Resistance to dry-heat test (Annex 11, paragraph 6. test procedure);

(f) Ozone ageing test (Annex 11, paragraph 7. test procedure);

(g) Temperature cycle test (Annex 11, paragraph 8. test procedure);

(h) Flex line cycle test (Annex 11, paragraph 9. test procedure).

10. Part VI – Specifications of vehicle fuel system incorporating LHSS

This part specifies requirements for the integrity of the hydrogen fuel delivery system, which includes the liquefied hydrogen storage system, piping, joints, and components in which hydrogen is present. The fuelling receptacle label shall designate liquid hydrogen as the fuel type. Test procedures are given in Annex 12.

10.1. In-use fuel system integrity

10.1.1. Fuelling receptacle requirements

10.1.1.1. A label shall be affixed close to the fuelling receptacle; for instance, inside a refilling hatch, showing the following information: fuel type (e.g. "LH_2" for liquefied hydrogen), NWP, MFP, date of removal from service of containers.

10.1.1.2. 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.

10.1.1.3. 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.

10.1.1.4. If appropriate, the geometry of the fuelling receptacle of liquefied hydrogen gas vehicles may be at the manufacturer's discretion and in agreement with the technical service in absence of a standard.

10.2. In-use fuel system integrity

10.2.1. 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 over-pressure protection shall comply with the installation verification referred to in Annex 12, paragraph 6.

10.2.2. Hydrogen discharge systems

10.2.2.1. Pressure relief systems

Pressure relief devices (such as a burst disc) shall comply with the installation verification referred to in Annex 12, paragraph 6. and may be used outside the hydrogen storage system. The hydrogen gas discharge from other pressure relief devices shall not be directed:

(a) towards exposed electrical terminals, exposed electrical switches or other ignition sources;

(b) into or towards the vehicle passenger or luggage compartments;

(c) into or towards any vehicle wheel housing; and

(d) towards hydrogen gas containers.

10.2.2.2. Vehicle exhaust system

10.2.2.2.1. The vehicle exhaust system shall comply with the test for the vehicle exhaust system referred to in Annex 12, paragraph 4.

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

(a) Not exceed 4 % average by volume during any moving three-second time interval during normal operation including start-up and shutdown; and

(b) Not exceed 8 % at any time.

10.2.3. Protection against flammable conditions: single failure conditions

10.2.3.1. Hydrogen leakage and/or permeation from the hydrogen storage system shall not directly vent into the passenger, luggage, or cargo compartments, or to any enclosed or semi-enclosed spaces within the vehicle that contains unprotected ignition sources.

10.2.3.2. Any single failure downstream of the main hydrogen shut off valve shall not result in any level of a hydrogen concentration in anywhere in the passenger compartment according to test procedure referred to in Annex 12, paragraph 3.2.

10.2.3.3. If, during operation, a single failure results in a hydrogen concentration exceeding 3 % by volume in air in the enclosed or semi-enclosed spaces of the vehicle, then a warning shall be provided (paragraph 10.2.3.5.). If the hydrogen concentration exceeds 4 % by volume in the air in the enclosed or semi-enclosed spaces of the vehicle, the main shutoff valve shall be closed to isolate the storage system. (Annex 12, paragraph 3. test procedure).

10.2.3.4. 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 12, paragraph 5. test procedure).

10.2.3.5. 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;

(b) Yellow in colour if the detection system malfunctions (e.g. circuit disconnection, short-circuit, sensor fault). It shall be red in compliance with paragraph 10.2.3.3.

(c) When illuminated, shall be visible to the driver under both daylight and night time driving conditions; and

(d) Remains illuminated when 3 % concentration or detection system malfunction) exists and the master control is in the 'on' position or the propulsion system is otherwise activated.

10.2.3.6 Identification of hydrogen fuelled vehicles.

On vehicles of the categories M_2/N_2 and M_3/N_3, equipped with a liquefied hydrogen system, labels shall be installed as specified in Annex 6 – Part 2.

These labels shall be placed on the front of the vehicle and on the left side as well as on the right side of the vehicle; for the side in vicinity of a front door, if available. If there is no front door available, the label must be placed on the first third of the vehicle length. In addition, for vehicles of category M_2 and M_3, a label shall be fixed to the rear of the vehicle.

10.3. Post-crash fuel system integrity

The vehicle fuel system shall comply with the following requirements after the vehicle crash tests in accordance with the following UN Regulations by also applying the test procedures prescribed in Annex 12 to this Regulation.

(a) Frontal impact test procedures in accordance with either Regulation No. 12, or Regulation No. 94, Annex 3 and Regulation No. 137, Annex 3 only to the extent where the Regulations apply as prescribed in their scope; and

(b) Lateral impact test procedures in accordance with UN Regulation No. 95, Annex 4.

At the request of the manufacturer, for vehicles not in the scope of these UN Regulations and that are derived from M_1 or N_1 vehicle categories, they may be tested in accordance with the crash test procedures in these UN Regulations.

This requirement is deemed to be met if the vehicle equipped with LHSS is approved in accordance with UN Regulation No. 94 (05 series of amendments or later) or UN Regulation No. 137 (03 series of amendments or later) for frontal impact and UN Regulation No. 95 (06 series of amendments or later) for lateral impact, as applicable in the scope of aforementioned crash regulations.

Where one or more of these crash tests are not required, the LHSS, including the safety devices affixed to it shall be installed in such a way that the following accelerations can be absorbed without breaking of the fixation or loosening of the filled LHSS container(s):

Vehicle of categories M_1 and N_1:

(a) 20 g in forward and rearward direction of travel; and

(b) 8 g horizontally perpendicular to the direction of travel.

Vehicles of categories M_2 and N_2:

(a) 10 g in forward direction of travel; and

(b) 5 g horizontally perpendicular to the direction of travel.

Vehicles of categories M_3 and N_3:

(a) 6.6 g in the forward direction of travel; and

(b) 5 g horizontally perpendicular to the direction of travel.

Any substitute mass used shall be representative for a fully equipped and filled LHSS container/assembly.

10.3.1. Fuel leakage limit

The volumetric flow of hydrogen gas leakage shall not exceed an average of 118 NL per minute for 60 minutes after the crash as determined in accordance with Annex 12, paragraph 1.

10.3.2. Concentration limit in enclosed spaces

Hydrogen gas leakage shall not result in a hydrogen concentration in the air greater than 4 % by volume in the passenger and luggage compartments (Annex 12, paragraph 2. test procedures). The requirement is satisfied if it is confirmed that the shut-off valve of the storage system has closed within 5 seconds of the crash and no leakage from the storage system.

10.3.3. Container Displacement

The storage container(s) shall remain attached to the vehicle at a minimum of one attachment point.

10.4. Flammable materials used in the vehicle shall be protected from liquefied air that may condense on elements of the fuel system.

10.5. The insulation of the components shall prevent liquefaction of the air in contact with the outer surfaces, unless a system is provided for collecting and vaporizing the liquefied air. The materials of the components nearby shall be compatible with an atmosphere enriched with oxygen. "

Renumber paragraphs 8 to 13… (former) to 11 to 16…:

16. Transitional provisions

…[to be discussed]

Amend Annex 6, to read:

"Annex 6 – Part 1

Provisions for a label for compressed hydrogen vehicles of categories M_2/N_2 and M_3/N_3.

…"

Insert new Annex 6 – Part 2, to read:

"Annex 6 – Part 2

Provisions for a label for liquefied hydrogen vehicles of categories M_2/N_2 and M_3/N_3.

(Paragraph 7. of this Regulation)

The label consists of a sticker which shall be weather resistant.

The centre zone indicates the first energy source.

The upper zone indicates the second energy source.

The left zone indicates the gas behaviour due to density.

The right zone indicates the state of aggregation of stored liquefied fuel.

Layout and symbols shall be in accordance with ISO 17840-4:2018.

The colour and dimensions of the sticker shall fulfil the following requirements:

Colours:

Background : white

Border : light blue or light blue reflecting, RGB code 0, 176, 240

Letters and symbols : light blue or light blue reflecting, RGB code 0, 176, 240

Dimensions:

Sticker width: ≥ 110 mm

Sticker height: ≥ 80 mm"

Insert new Annexes 10 to 12, to read:

"Annex 10

Test procedures for LHSS design qualification

1. Verification tests for Baseline metrics

1.1. Proof pressure test

The inner container and the pipe work situated between the inner container and the outer jacket shall withstand an inner pressure test at room temperature according to the following requirements.

The test pressure p_{test} is defined by the manufacturer and shall fulfil the following requirements:

$p_{test} \geq 1.3$ (MAWP ± 0.1 MPa)

(a) For metallic containers, either p_{test} is equal to or greater than the maximum pressure of the inner container during fault management (as determined in Annex 10, paragraph 2.3.) or the manufacturer proves by calculation that at the maximum pressure of the inner container during fault management no yield occurs;

(b) For non-metallic containers, p_{test} is equal to or greater than the maximum pressure of the inner container during fault management (as determined in Annex 10, paragraph 2.3.).

The test is conducted according to the following procedure:

(a) The test is conducted on the inner storage container and the interconnecting pipes between inner storage container and vacuum jacket before the outer jacket is mounted;

(b) The test is either conducted hydraulically with water or a glycol/water mixture, or alternatively with gas. The container is pressurized to test pressure ptest at an even rate and kept at that pressure for at least 10 minutes;

(c) The test is done at ambient temperature. In the case of using gas to pressurize the container, the pressurization is done in a way that the container temperature stays at or around ambient temperature.

The test is passed successfully if, during the first 10 minutes after applying the proof pressure, no visible permanent deformation, no visible degradation in the container pressure and no visible leakage are detectable.

1.2. Baseline initial burst pressure

The test is conducted according to the following procedure:

(a) The test is conducted on the inner container at ambient temperature;

(b) The test is conducted hydraulically with water or a water/glycol mixture;

(c) The pressure is increased at a constant rate, not exceeding 0.5 MPa/min until burst or leakage of the container occurs;

(d) When MAWP is reached there is a wait period of at least ten minutes at constant pressure, during which time the deformation of the container can be checked;

(e) The pressure is recorded or written during the entire test.

For steel inner containers, the test is passed successfully if at least one of the two passing criteria described in paragraph 5.1.2. of this Regulation is fulfilled. For inner containers made out of an aluminium alloy or other material, a passing criterion shall be defined which guarantees at least the same level of safety compared to steel inner containers.

1.3. Baseline pressure cycle life

Containers and/or vacuum jackets are pressure cycled with a number of cycles at least three times the number of possible full pressure cycles (from the lowest to highest operating pressure) for an expected on-road performance. The number of pressure cycles is defined by the manufacturer under consideration of operating pressure range, size of the storage and, respectively, maximum number of refuellings and maximum number of pressure cycles under extreme usage and storage conditions. Pressure cycling is conducted between atmospheric pressure and MAWP at liquid nitrogen temperatures, e.g. by filling the container with liquid nitrogen to certain level and alternately pressurizing and depressurizing it with (pre-cooled) gaseous nitrogen or helium.

2. Verification for expected on-road performance

2.1. Boil-off test

The test is conducted according to the following procedure:

(a) For pre-conditioning, the container is fuelled with liquid hydrogen to the specified maximum filling level. Hydrogen is subsequently extracted until it meets half filling level, and the system is allowed to completely cool down for at least 24 hours and a maximum of 48 hours;

(b) The container is filled to the specified maximum filling level;

(c) The container is pressurized until boil-off pressure is reached;

(d) The test lasts for at least another 48 hours after boil-off started and is not terminated before the pressure stabilizes. Pressure stabilization has occurred when the average pressure does not increase over a two hour period.

The pressure of the inner container is recorded or written during the entire test. The test is passed successfully if the following requirements are fulfilled:

(a) The pressure stabilizes and stays below MAWP during the whole test;

(b) The pressure relief devices are not allowed to open during the whole test.

The pressure of the inner container shall be recorded or written during the entire test. The test is passed when the following requirements are fulfilled:

(a) The pressure shall stabilize and stay below MAWP during the whole test;

(b) The pressure relief devices are not allowed to open during the whole test.

2.2. Leak test

The test shall be conducted according to the procedure described in Annex 4, paragraph 2.

2.3. Vacuum loss test

The first part of the test is conducted according to the following procedure:

(a) The vacuum loss test is conducted with a completely cooled-down container (according to the procedure in Annex 10, paragraph 2.1.);

(b) The container is filled with liquid hydrogen to the specified maximum filling level;

(c) The vacuum enclosure is flooded with air at an even rate to atmospheric pressure;

(d) The test is terminated when the first pressure relief device does not open any more.

The pressure of the inner container and the vacuum jacket is recorded or written during the entire test. The opening pressure of the first safety device is recorded or written. The first part of test is passed if the following requirements are fulfilled:

(a) The first pressure relief device opens below or at MAWP and limit the pressure to not more than 110 per cent of the MAWP;

(b) The first pressure relief device does not open at pressure above MAWP;

(c) The secondary pressure relief device does not open during the entire test.

After passing the first part, the test shall be repeated subsequently to re-generation of the vacuum and cool-down of the container as described above.

(a) The vacuum is re-generated to a value specified by the manufacturer. The vacuum shall be maintained at least 24 hours. The vacuum pump may stay connected until the time directly before the start of the vacuum loss;

(b) The second part of the vacuum loss test is conducted with a completely cooled-down container (according to the procedure in Annex 10, paragraph 2.1.);

(c) The container is filled to the specified maximum filling level;

(d) The line downstream the first pressure relief device is blocked and the vacuum enclosure is flooded with air at an even rate to atmospheric pressure;

(e) The test is terminated when the second pressure relief device does not open any more.

The pressure of the inner container and the vacuum jacket is recorded or written during the entire test. For steel containers the second part of the test is passed if the secondary pressure relief device does not open below 110 per cent of the set pressure of the first pressure relief device and limits the pressure in the container to a maximum 136 per cent of the MAWP if a safety valve is used, or, 150 per cent of the MAWP if a burst disk is used as the secondary pressure relief device. For other container materials, an equivalent level of safety shall be demonstrated.

3. Verification test for service-terminating performance due to fire

The tested liquefied hydrogen storage system shall be representative of the design and the manufacturing of the type to be homologated. Its manufacturing shall be completely finished and it shall be mounted with all its equipment.

The first part of the test is conducted according to the following procedure:

(a) The bonfire test is conducted with a completely cooled-down container (according to the procedure in Annex 10, paragraph 2.1.);

(b) The container contained during the previous 24 hours a volume of liquid hydrogen at least equal to half of the water volume of the inner container;

(c) The container is filled with liquid hydrogen so that the quantity of liquid hydrogen measured by the mass measurement system is half of the maximum allowed quantity that may be contained in the inner container;

(d) A fire burns 0.1 m underneath the container. The length and the width of the fire exceed the plan dimensions of the container by 0.1 m. The temperature of the fire is at least 590 °C. The fire shall continue to burn for the duration of the test;

(e) The pressure of the container at the beginning of the test is between 0 MPa and 0.01 MPa at the boiling point of hydrogen in the inner container;

(f) The test shall continue until the storage pressure decreases to or below the pressure at the beginning of the test, or alternatively in case the first PRD is a re-closing type, the test shall continue until the safety device has opened for a second time;

(g) The test conditions and the maximum pressure reached within the container during the test are recorded in a test certificate signed by the manufacturer and the technical service.

The test is passed if the following requirements are fulfilled:

(a) The secondary pressure relief device is not operated below 110 per cent of the set pressure of the primary pressure relief device;

(b) The container shall not burst and the pressure inside the inner container shall not exceed the permissible fault range of the inner container.

The permissible fault range for steel containers is as follows:

(a) If a safety valve is used as secondary pressure relief device, the pressure inside the container does not exceed 136 per cent of the MAWP of the inner container;

(b) If a burst disc is used outside the vacuum area as secondary pressure relief device, the pressure inside the container is limited to 150 per cent of the MAWP of the inner container;

(c) If a burst disc is used inside the vacuum area as secondary pressure relief device, the pressure inside the container is limited to 150 per cent of the MAWP ± 0.1 MPa of the inner container.

For other materials, an equivalent level of safety shall be demonstrated.

Annex 11

Test procedures for specific component for LHSS

The test procedures for pressure relief devices (paragraph 9.1. of this Regulation) and shut-off valves (paragraph 9.2. of this Regulation) are described below:

Testing shall be performed with hydrogen gas having gas quality compliant with ISO 14687:2025/SAE J2719_202003. All tests shall be performed at ambient temperature 20(±5) °C unless otherwise specified.

1. Pressure test

A hydrogen containing component shall withstand without any visible evidence of leak or deformation a test pressure of 150 per cent MAWP with the outlets of the high-pressure part plugged. The pressure shall subsequently be increased from 150 per cent to 300 per cent MAWP. The component shall not show any visible evidence of rupture or cracks.

The pressure supply system shall be equipped with a positive shut-off valve and a pressure gauge having a pressure range of not less than 150 per cent and no more than 200 per cent of the test pressure; the accuracy of the gauge shall be 1 per cent of the pressure range.

For components requiring a leakage test, this test shall be performed prior to the pressure test.

2. External leakage test

A component shall be free from leakage through stem or body seals or other joints and shall not show evidence of porosity in casting when tested as described in Annex 11, paragraph 3.3. at any gas pressure between zero and its MAWP.

The test shall be performed on the same equipment at the following conditions:

(a) At ambient temperature;

(b) At the minimum operating temperature or at liquid nitrogen temperature after sufficient conditioning time at this temperature to ensure thermal stability;

(c) At the maximum operating temperature after sufficient conditioning time at this temperature to ensure thermal stability.

During this test, the equipment under test shall be connected to a source of gas pressure. A positive shut-off valve and a pressure gauge having a pressure range of not less than 150 per cent and not more than 200 per cent of the test pressure shall be installed in the pressure supply piping; the accuracy of the gauge shall be 1 per cent of the pressure range. The pressure gauge shall be installed between the positive shut-off valve and the sample under test.

Throughout the test, the sample shall be tested for leakage, with a surface-active agent without formation of bubbles or measured with a leakage rate less than 216 Nml/hr.

3. Endurance test

3.1. A component shall be capable of conforming to the applicable leakage test requirements of Annex 11, paragraphs 2. and 9., after being subjected to 20,000 operation cycles.

3.2. The appropriate tests for external leakage and seat leakage, as described in Annex 11, paragraphs 2. and 9. shall be carried out immediately following the endurance test.

3.3. The shut-off valve shall be securely connected to a pressurized source of dry air or nitrogen and subjected to 20,000 operation cycles. A cycle shall consist of one opening and one closing of the component within a period of not less than 10 ± 2 seconds.

3.4. The component shall be operated through 96 per cent of the number of specified cycles at ambient temperature and at the MAWP of the component. During the off cycle the downstream pressure of the test fixture shall be allowed to decay to 50 per cent of the MAWP of the component.

3.5. The component shall be operated through 2 per cent of the total cycles at the maximum material temperature (-40 °C to +85 °C) after sufficient conditioning time at this temperature to ensure thermal stability and at MAWP. The component shall comply with Annex 11, paragraphs 2. and 9. at the appropriate maximum material temperature (-40 °C to +85 °C) at the completion of the high temperature cycles.

3.6. The component shall be operated through 2 per cent of the total cycles at the minimum material temperature (-40 °C to +85 °C) but not less than the temperature of liquid nitrogen after sufficient conditioning time at this temperature to ensure thermal stability and at the MAWP of the component. The component shall comply with Annex 11, paragraphs 2. and 9. at the appropriate minimum material temperature (-40 °C to +85 °C) at the completion of the low temperature cycles.

4. Operational test

The operational test shall be carried out in accordance with EN 13648-1:2009 or EN 13648-2:2002. The specific requirements of the standard are applicable.

5. Corrosion resistance test

Metallic hydrogen components shall comply with the leakage tests referred to in Annex 11, paragraphs 2. and 9. after being submitted to 144 hours salt spray test according to ISO 9227:2022 with all connections closed.

A copper or brass hydrogen containing component shall comply with the leakage tests referred to in Annex 11, paragraphs 2. and 9. and after being submitted to 24 hours immersion in ammonia according to ISO 6957:1988 with all connections closed.

6. Resistance to dry-heat test

The test shall be carried out in compliance with ISO 188:2023. The test piece shall be exposed to air at a temperature equal to the maximum operating temperature for 168 hours. The change in tensile strength shall not exceed ±25 per cent. The change in ultimate elongation shall not exceed the following values:

- **maximum increase 10 per cent;**

- **maximum decrease 30 per cent.**

7. Ozone ageing Test

The test shall be in compliance with ISO 1431-1:2024. The test piece, which shall be stressed to 20 per cent elongation, shall be exposed to air at +40 °C with an ozone concentration of 50 parts per hundred million during 120 hours.

No cracking of the test piece is allowed.

8. Temperature cycle test

A non-metallic part containing hydrogen shall comply with the leakage tests referred to in Annex 11, paragraphs 2. and 9. after having been submitted to a 96-hour temperature cycle from the minimum operating temperature up to the maximum operating temperature with a cycle time of 120 minutes, under MAWP.

9. Flex line cycle test

Any flexible fuel line shall be capable of conforming to the applicable leakage test requirements referred to in Annex 11, paragraph 2., after being subjected to 6,000 pressure cycles.

The pressure shall change from atmospheric pressure to the MAWP of the container within less than five seconds, and after a time of at least five seconds, shall decrease to atmospheric pressure within less than five seconds.

The appropriate test for external leakage, as referred to in Annex 11, paragraph 2., shall be carried out immediately following the endurance test.

Annex 12

Test procedures for a vehicle fuel system incorporating LHSS

The test procedures for vehicle fuel systems incorporating LHSS according to paragraphs 1., 2. and 7. of this annex apply only to vehicles of categories M1 and N1 that are subjected to one or more crash tests.

1. Post-crash liquefied hydrogen storage system leak test

Prior to conducting the crash test, instrumentation is installed in the hydrogen storage system to perform the required pressure and temperature measurements if the standard vehicle does not already have instrumentation with the required accuracy.

The storage system is then purged, if necessary, following manufacturer directions to remove impurities from the container before filling the storage system with compressed hydrogen or helium gas. Since the storage system pressure varies with temperature, the targeted fill pressure is a function of the temperature. The target pressure shall be determined from the following equation:

$$P_{target} = NWP \times (273 + To) / 288$$

where NWP is the nominal working pressure (MPa), To is the ambient temperature to which the storage system is expected to settle, and P_{target} is the targeted fill pressure after the temperature settles.

The container is filled to a minimum of 95 % of the targeted fill pressure and allowed to settle (stabilize) prior to conducting the crash test.

The main stop valve and shut-off valves for hydrogen gas, located in the downstream hydrogen gas piping, are kept open immediately prior to the impact.

1.1. Post-crash leak test - compressed hydrogen storage system filled with compressed hydrogen

The hydrogen gas pressure, P0 (MPa), and temperature, T0 (°C), is measured immediately before the impact and then at a time interval, Δt (min), after the impact. The time interval, Δt, starts when the vehicle comes to rest after the impact and continues for at least 60 minutes. The time interval, Δt, is increased, if necessary, in order to accommodate measurement accuracy for a storage system with a large volume operating up to 70 MPa; in that case, Δt can be calculated from the following equation:

$$\Delta t = V_{CHSS} \times NWP / 1\,000 \times ((-0.027 \times NWP + 4) \times Rs - 0.21) - 1.7 \times Rs$$

where Rs = Ps / NWP, Ps is the pressure range of the pressure sensor (MPa), NWP is the Nominal Working Pressure (MPa), V_{CHSS} is the volume of the compressed hydrogen storage system (L), and Δt is the time interval (min). If the calculated value of Δt is less than 60 minutes, Δt is set to 60 minutes.

The initial mass of hydrogen in the storage system can be calculated as follows:

$$P_o' = P_o \times 288 / (273 + T_0)$$

$$P_o' = -0.0027 \times (P_0')^2 + 0.75 \times P_0' + 0.5789$$

$$M_o = \rho_o' \times V_{CHSS}$$

Correspondingly, the final mass of hydrogen in the storage system, M_f, at the end of the time interval, Δt, can be calculated as follows:

$$P_f' = P_f \times 288 / (273 + T_f)$$

$$\rho_f' = -0.0027 \times (P_f')^2 + 0.75 \times P_f' + 0.5789$$

$$M_f = \rho_f' \times V_{CHSS}$$

where P_f is the measured final pressure (MPa) at the end of the time interval, and T_f is the measured final temperature (°C).

The average hydrogen flow rate over the time interval (that shall be less than the criteria in paragraph 7.3.1.) is therefore:

$$V_{H2} = (M_f - M_o) / \Delta t \times 22.41 / 2.016 \times (P_{target} / P_o)$$

where V_{H2} is the average volumetric flow rate (NL/min) over the time interval and the term (P_{target} /P_o) is used to compensate for differences between the measured initial pressure, P_o, and the targeted fill pressure P_{target}.

1.2. Post-crash leak test - Compressed hydrogen storage system filled with compressed helium

The helium gas pressure, P_0 (MPa), and temperature T_0 (°C), are measured immediately before the impact and then at a predetermined time interval after the impact. The time interval, Δt, starts when the vehicle comes to rest after the impact and continues for at least 60 minutes.

The time interval, Δt, shall be increased, if necessary, in order to accommodate measurement accuracy for a storage system with a large volume operating up to 70MPa; in that case, Δt can be calculated from the following equation:

$$\Delta t = V_{CHSS} \times NWP / 1\,000 \times ((-0.028 \times NWP + 5.5) \times R_s - 0.3) - 2.6 \times R_s$$

where $R_s = P_s / NWP$, P_s is the pressure range of the pressure sensor (MPa), NWP is the Nominal Working Pressure (MPa), V_{CHSS} is the volume of the compressed hydrogen storage system (L), and Δt is the time interval (min). If the value of Δt is less than 60 minutes, Δt is set to 60 minutes.

The initial mass of hydrogen in the storage system is calculated as follows:

$$P_o' = P_o \times 288 / (273 + T_0)$$

$$\rho_o' = -0.0043 \times (P_0')^2 + 1.53 \times P_0' + 1.49$$

$$M_o = \rho_o' \times V_{CHSS}$$

The final mass of hydrogen in the storage system at the end of the time interval, Δt, is calculated as follows:

$$P_f' = P_f \times 288 / (273 + T_f)$$

$$\rho_f' = -0.0043 \times (P_f')^2 + 1.53 \times P_f' + 1.49$$

$$M_f = \rho_f' \times V_{CHSS}$$

where P_f is the measured final pressure (MPa) at the end of the time interval, and T_f is the measured final temperature (°C).

The average helium flow rate over the time interval is therefore

$$V_{He} = (M_f - M_o) / \Delta t \times 22.41 / 4.003 \times (P_o / P_{target})$$

where V_{He} is the average volumetric flow rate (NL/min) over the time interval and the term P_o / P_{target} is used to compensate for differences between the measured initial pressure (P_o) and the targeted fill pressure (P_{target}).

Conversion of the average volumetric flow of helium to the average hydrogen flow is done with the following expression:

$$V_{H2} = V_{He} / 0.75$$

where V_{H2} is the corresponding average volumetric flow of hydrogen (that shall be less than the criteria in paragraph 7.3.1. of this Regulation to pass).

2. Post-crash concentration test for enclosed spaces

2.1. The measurements are recorded in the crash test that evaluates potential hydrogen (or helium) leakage as determined in accordance with paragraph 1.

2.2. Sensors are selected to measure either the build-up of the hydrogen or helium gas or the reduction in oxygen (due to displacement of air by leaking hydrogen/helium).

2.3. Sensors are calibrated to traceable references to ensure an accuracy of ±5 % at the targeted criteria of 4 % hydrogen or 3 % helium by volume in air, and a full-scale measurement capability of at least 25 % above the

target criteria. The sensor shall be capable of a 90 % response to a full-scale change in concentration within 10 seconds.

2.4. Prior to the crash impact, the sensors are located in the passenger and luggage compartments of the vehicle as follows:

(a) At a distance within 250 mm of the headliner above the driver's seat or near the top centre the passenger compartment;

(b) At a distance within 250 mm of the floor in front of the rear (or rear most) seat in the passenger compartment;

(c) At a distance within 100 mm of the top of luggage compartments within the vehicle that are not directly affected by the particular crash impact to be conducted.

2.5. The sensors are securely mounted on the vehicle structure or seats and protected for the planned crash test from debris, air bag exhaust gas and projectiles. The measurements following the crash are recorded by instruments located within the vehicle or by remote transmission.

2.6. The vehicle may be located either outdoors in an area protected from the wind and possible solar effects or indoors in a space that is large enough or ventilated to prevent the build-up of hydrogen to more than 10 % of the targeted criteria in the passenger, luggage, and cargo compartments.

2.7. Post-crash data collection in enclosed spaces commences when the vehicle comes to a rest. Data from the sensors are collected at least every 5 seconds and continue for a period of 60 minutes after the test. A first-order lag (time constant) up to a maximum of 5 seconds may be applied to the measurements to provide "smoothing" and filter the effects of spurious data points.

2.8. The filtered readings from each sensor shall be below the targeted criteria of 3 ± 1.0 % for hydrogen or 2.25 ± 0.75 % for helium at all times throughout the 60 minutes post-crash test period.

3. Compliance test for single failure conditions

Either test procedure of paragraph 3.1. or paragraph 3.2. shall be executed:

3.1. Test procedure for vehicle equipped with hydrogen gas leakage detectors

3.1.1. Test condition

3.1.1.1. 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.

3.1.1.2. Test gas: Two mixtures of air and hydrogen gas: 2 ± 1.0 % concentration (or less) of hydrogen in the air to verify function of the warning, and 3 ± 1.0 % concentration (or less) of hydrogen in the air to verify function of the shut-down. The proper concentrations are selected based on the recommendation (or the detector specification) by the manufacturer.

3.1.2. Test method

3.1.2.1. 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.

3.1.2.2. 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.

3.2. Test procedure for integrity of enclosed spaces and detection systems.

3.2.1. Preparation:

The test is conducted without any influence of wind.

Special attention is paid to the test environment as during the test flammable mixtures of hydrogen and air may occur.

3.2.1.1. 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 shutoff 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.

3.2.1.2. 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 10.2.3.2. 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 10.2.3.1.

3.2.2. Procedure:

Vehicle doors, windows and other covers are closed.

The propulsion system is started, allowed to warm up to its normal operating temperature and left operating at idle for the test duration.

A leak is simulated using the remote controllable function.

The hydrogen concentration is measured continuously until the concentration does not rise for 3 minutes. When testing for compliance with paragraph 10.2.3.3. of this Regulation, the simulated leak is then increased using the remote controllable function until the main hydrogen shutoff 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.

When testing for compliance with paragraph 10.2.3.2. of this Regulation, the test is successfully completed if the hydrogen concentration in the passenger compartment does not exceed 1.0 %. When testing for compliance with paragraph 10.2.3.3. 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 10.2.3.3. of this Regulation; otherwise, the test is failed and the system is not qualified for vehicle service.

4. Compliance test for the vehicle exhaust system

4.1. The power system of the test vehicle (e.g. fuel cell stack or engine) is warmed up to its normal operating temperature.

4.2. The measuring device is warmed up before use to its normal operating temperature.

4.3. 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.

4.4. 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; and

(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.

4.5. The measurement device shall have a measurement response time of less than 300 milliseconds.

5. Compliance test for fuel line leakage

5.1. 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.

5.2. 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.

5.3. Hydrogen leak detection is performed primarily at joints.

5.4. **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.**

5.5. **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 in order to check for bubbles caused by trace leaks.**

6. **Installation verification**

The system is visually inspected for compliance.

7. **Post-crash leak test for the liquefied hydrogen storage systems**

Prior to the vehicle crash test, the following steps are taken to prepare the liquefied hydrogen storage system (LHSS):

(a) **If the vehicle does not already have the following capabilities as part of the standard vehicle; the following shall be installed before the test:**

- **LHSS pressure sensor. The pressure sensor shall have a full scale of reading of at least 150 % of MAWP, an accuracy of at least 1 % of full scale, and capable of reading values of at least 10 kPa;**
- **LHSS temperature sensor. The temperature sensor shall be capable of measuring cryogenic temperatures expected before crash. The sensor is located on an outlet, as near as possible to the container;**

(b) **Fill and drain ports. The ability to add and remove both liquefied and gaseous contents of the LHSS before and after the crash test shall be provided;**

(c) **The LHSS is purged with at least 5 volumes of nitrogen gas;**

(d) **The LHSS is filled with nitrogen to the equivalence of the maximum fill level of hydrogen by weight;**

(e) **After fill, the (nitrogen) gas vent is to be closed, and the container allowed to equilibrate.**

The leak-tightness of the LHSS is confirmed.

After the LHSS pressure and temperature sensors indicate that the system has cooled and equilibrated, the vehicle shall be crashed per state or regional regulation. Following the crash, there shall be no visible leak of cold nitrogen gas or liquid for a period of at least 1 hour after the crash. Additionally, the operability of the pressure controls or PRDs shall be proven to ensure that the LHSS is protected against burst after the crash. If the LHSS vacuum has not been compromised by the crash, nitrogen gas may be added to the LHSS via the fill / drain port until pressure controls and/or PRDs are activated. In the case of re-closing pressure controls or PRDs, activation and re-closing for at least 2 cycles shall be demonstrated.

Exhaust from the venting of the pressure controls or the PRDs shall not be vented to the passenger or luggage, compartments during these post-crash tests.

Either test procedure referred to in paragraph 7.1. or the alternative test procedure in paragraph 7.2. (consisting of paragraphs 7.2.1. and 7.2.2.) may be chosen at the discretion of the manufacturer.

7.1. Post-crash leak test for the liquefied hydrogen storage systems

7.1.1. Following confirmation that the pressure control and/or safety relief valves are still functional, the leak tightness of the LHSS may be proven by detecting all possible leaking parts with a sniff sensor of a calibrated Helium leak test device used in sniff modus. The test can be performed as an alternative if the following pre-conditions are fulfilled:

(a) No possible leaking part shall be below the liquid nitrogen level as indicated on the storage container;

(b) All possible leaking parts are pressurized with helium gas when the LHSS is pressurized;

(c) Required covers and/or body panels and parts can be removed to gain access to all potential leak sites.

7.1.2. Prior to the test the manufacturer shall provide a list of all possible leaking parts of the LHSS. Possible leaking parts are:

(a) Any connectors between pipes and between pipes and the container;

(b) Any welding of pipes and components downstream the container;

(c) Valves;

(d) Flexible lines;

(e) Sensors.

7.1.3. Prior to the leak test overpressure in the LHSS should be released to atmospheric pressure and afterwards the LHSS should be pressurized with helium to at least the operating pressure but well below the normal pressure control setting (so the pressure regulators do not activate during the test period). The test is passed if the total leakage amount (i.e. the sum of all detected leakage points) is less than 216 Nml/hr.

7.2. Alternative post-crash tests for the liquefied hydrogen storage systems

Both tests of paragraphs 7.2.1. and 7.2.2. are conducted under the test procedure referred to in of paragraph 7.2.

7.2.1. Alternative post-crash leak test

7.2.1.1. Following confirmation that the pressure control and/or safety relief valves are still functional, the following test may be conducted to measure

the post-crash leakage. The concentration test described in Annex 12, paragraph 1.2. shall be conducted in parallel for the 60-minute test period if the hydrogen concentration has not already been directly measured following the vehicle crash.

7.2.1.2. The container shall be vented to atmospheric pressure and the liquefied contents of the container shall be removed and the container shall be heated up to ambient temperature. The heat-up could be done, e.g. by purging the container sufficient times with warm nitrogen or increasing the vacuum pressure.

7.2.1.3. If the pressure control set point is less than 90 % of the MAWP, the pressure control shall be disabled so that it does not activate and vent gas during the leak test.

7.2.1.4. The container shall then be purged with helium by either:

(a) flowing at least 5 volumes through the container; or

(b) pressurizing and de-pressurizing the container the LHSS at least 5 times.

7.2.1.5. The LHSS shall then be filled with helium to 80 % of the MAWP of the container or to within 10 % of the primary relief valve setting, whichever results in the lower pressure, and held for a period of 60 minutes. The measured pressure loss over the 60-minute test period shall be less than or equal to the following criterion based on the liquid capacity of the LHSS:

(a) 0.20 MPa allowable loss for 100 l systems or less;

(b) 0.10 MPa allowable loss for systems greater than 100 l and less than or equal to 200 l; and

(c) 0.05 MPa allowable for systems greater than 200 l.

7.2.2. Post-crash enclosed spaces test

7.2.2.1. The measurements shall be recorded in the crash test that evaluates potential liquid hydrogen leakage in test procedure paragraph 7.2.1. if the LHSS contains hydrogen for the crash test or during the helium leak test in test procedure in paragraph 2 of this annex.

7.2.2.2. Select sensors to measure the build-up of hydrogen or helium (depending which gas is contained within the Liquefied Hydrogen Storage Systems (LHSS) for the crash test). Sensors may measure either measure the hydrogen/helium content of the atmosphere within the compartments or measure the reduction in oxygen (due to displacement of air by leaking hydrogen/helium).

7.2.2.3. The sensors shall be calibrated to traceable references, have an accuracy of 5 % of reading at the targeted criteria of 4 % hydrogen (for a test with liquefied hydrogen) or 0.8 % helium by volume in the air (for a test at room temperature with helium), and a full-scale measurement capability

of at least 25 % above the target criteria. The sensor shall be capable of a 90 % response to a full-scale change in concentration within 10 seconds.

7.2.2.4. The installation in vehicles with LHSS shall meet the same requirements as for vehicles with compressed hydrogen storage systems in paragraph 2. Data from the sensors shall be collected at least every 5 seconds and continue for a period of 60 minutes after the vehicle comes to a rest if post-crash hydrogen is being measured or after the initiation of the helium leak test if helium build-up is being measured. Up to a 5 second rolling average may be applied to the measurements to provide "smoothing" and filter effects of spurious data paragraphs. The rolling average of each sensor shall be below the targeted criteria of 4 % hydrogen (for a test with liquefied hydrogen) or 0.8 % helium by volume in the air (for a test at room temperature with helium) at all times throughout the 60-minute post-crash test period. "