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## Economic Commission for Europe

### Inland Transport Committee

### World Forum for Harmonization of Vehicle Regulations

#### 195th session

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Item 4.8.2 of the provisional agenda

#### 1958 Agreement:

Consideration of draft amendments to existing

UN Regulations submitted by GRSG

## Proposal for 07 series of amendments to UN Regulation No. 105 (Vehicles for the carriage of dangerous goods)

### Submitted by the Working Party on General Safety Provisions\*

The text reproduced below was adopted by the Working Party on General Safety Provisions (GRSG) at its 128th session (ECE/TRANS/WP.29/GRSG/107, para. 46). It is based on GRSG-128-24-Rev.3. It is submitted to the World Forum for Harmonization of Vehicle Regulations (WP.29) and to the Administrative Committee (AC.1) for consideration at their March 2025 sessions.

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\* 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.



*Table of contents, amend to read:*

## "Contents

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1. Scope .....

...

### Annexes

- 1 Communication concerning the approval or extension or refusal or withdrawal of approval or production definitely discontinued of a vehicle type with regard to specific constructional features for the transport of dangerous goods .....
- 2 Arrangements of approval marks .....
- 3 Vehicles with a liquefied hydrogen storage system (LHSSs) .....

*Paragraph 5.1. (the table), amend to read:*

"

<i>Technical specifications</i>		<i>Vehicle designation (according to chapter 9.1 of Annex b to ADR)</i>				
		<i>EX/II</i>	<i>EX/III</i>	<i>AT</i>	<i>FL</i>	
...	...					
5.1.3.	Vehicle propulsion system					
5.1.3.2.	Fuel tanks and cylinders	X	X	X	X	
5.1.3.3.	Internal combustion engine	X	X	X	X	
5.1.3.3.1.	Engine	X	X	X	X	
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...	...	...	...	...	...	...
5.1.3.5.	Electric power train			X	X	
5.1.3.5.1.	General provisions			X	X	
5.1.3.5.2.	Rechargeable electrical energy system			X	X	
5.1.3.5.3.	Measures against thermal propagation				X	
5.1.3.5.4.	Vehicle charging inlet				X	
5.1.3.6.	Hydrogen fuel cell			X	X	
...	...	...	...	...	...	...

"

*Paragraph 5.1.1.1., amend to read*

"5.1.1.1. General provisions

The installation shall be so designed, constructed and protected that it cannot provoke any unintended ignition or short-circuit under normal conditions of use of vehicles.

The electrical installation shall meet the provisions of paragraphs 5.1.1.2. to 5.1.1.9. in accordance with the table of paragraph 5.1.

The electric power train and the high voltage components which are galvanically connected to it, which are in compliance with the technical provisions of UN Regulation No. 100<sup>4</sup>, as amended at least by the 03 series of amendments, need not to comply with the provisions of paragraph 5.1.1.2 to 5.1.1.7."

*Paragraph 5.1.1.3., amend to read (addition of a new item (g)):*

"5.1.1.3. Fuses and circuit breakers

All circuits shall be protected by fuses or automatic circuit breakers, except for the following:

- (a) From the starter battery to the cold start system;
- (b) From the starter battery to the alternator;
- (c) From the alternator to the fuse or circuit breaker box;
- (d) From the starter battery to the starter motor;
- (e) From the starter battery to the power control housing of the endurance braking system (see paragraph 5.1.2.1.), if this system is electrical or electromagnetic;
- (f) From the starter battery to the electrical lifting mechanism for lifting the bogie axle.
- (g) From the starter battery to the electric steering equipment.

The above unprotected circuits shall be as short as possible."

*Paragraph 5.1.1.8. to 5.1.1.8.5., amend to read:*

"5.1.1.8. De-energizing electrical circuits

5.1.1.8.1. Features to enable the de-energization of the electrical circuits for all voltage levels shall be placed as close to the battery as practicable. If the feature interrupts only one lead from the energy source, it shall interrupt the supply lead.

5.1.1.8.2. A control device to facilitate the de-energizing shall be installed in the driver's cab. It shall be readily accessible to the driver and ....

5.1.1.8.3. Features to enable the de-energization of the electrical circuits shall be designed so that they can be operated when the vehicle is stationary. The de-energization shall be completed within 30 seconds after the activation of the control device.

5.1.1.8.4. The feature shall be installed in such a way that IP65 protection complies with IEC 60529.

5.1.1.8.5. Cable connections on the feature

Systems with a voltage that exceeds 25 V AC or 60 V DC and systems under the scope of UN Regulation No. 100, shall comply with the requirements of the said regulation.

Systems with a voltage up to 25 V AC or 60 V DC shall have a protection degree IP 54 in accordance with IEC 60529. However, this does not apply if these connections are contained in a housing, which may be the battery box. In this case, it is sufficient to insulate the connections against short circuits, for example by a rubber cap."

*Paragraph 5.1.2.1., amend to read:*

"5.1.2.1. EX/II, EX/III, AT, FL and MEMU vehicles shall fulfil all relevant requirements of Regulation No. 13, including those of Annex 5.

Vehicles equipped with an electric regenerative braking system shall fulfil all relevant technical requirements of UN Regulation No. 13, as amended at least by the 11 series of amendments, as applicable.

Trailers with regenerative braking or electric power train are not allowed."

*Paragraph 5.1.3., amend to read:*

"5.1.3. Vehicle propulsion system

5.1.3.1. General provisions

The following technical provisions shall apply in accordance with the table of paragraph 5.1.

Hybrid vehicles equipped with an internal combustion engine and electric power train shall comply with the relevant provisions of 5.1.3.2. to 5.1.3.5."

*Paragraph 5.1.3.2., amend to read (delete the note, re-number the subparagraphs from (a) to (f)):*

"5.1.3.2. Fuel tanks and cylinders

The fuel tanks and cylinders supplying the engine of the vehicle shall meet the following requirements:

- (a) In the event of any leakage under normal conditions of carriage, the liquid fuel or the liquid phase of a gaseous fuel, shall drain to the ground and not come into contact with the load or hot parts of the vehicle;
- (b) Fuel tanks for liquid fuels shall meet the requirements of UN Regulation No. 34; fuel tanks containing petrol shall be equipped with an effective flame trap at the filler opening or with a closure enabling the opening to be kept hermetically sealed.
- (c) Fuel tanks and cylinders for LNG and for CNG respectively shall meet the relevant requirements of UN Regulation No. 110.
- (d) Fuel tanks for LPG shall meet the relevant requirements of UN Regulation No. 67;
- (e) Fuel tanks and cylinders for hydrogen shall meet the relevant requirements of UN Regulation No. 134, at least series 02 of amendments or for liquid hydrogen containers the technical provisions as reproduced in Annex XX to this Regulation.
- (f) The discharge opening(s) of pressure relief devices and/or pressure relief valves of fuel tanks containing gaseous fuels shall be directed away from air intakes, fuel tanks, the load or hot parts of the vehicle and shall not impinge on enclosed areas, other vehicles, exterior-mounted systems with air intake (i.e. air conditioning systems), engine intakes, electrical storage systems or engine exhaust. Pipes of the fuel system shall not be fixed on the shell containing the load."

*Paragraph 5.1.3.3., amend to read:*

"5.1.3.3. Internal combustion engine

5.1.3.3.1. Engine

The engine propelling the vehicle shall be so equipped and situated to avoid any danger to the load through heating or ignition.

The use of a fuel shall only be permitted if components are approved and installation meet the provisions of paragraph 5.1.1. and the technical requirements of:

- (a) UN Regulation No. 110 for CNG or LNG.
- (b) UN Regulation No. 67 for LPG.
- (c) UN Regulation No. 134 for compressed hydrogen and the technical provisions for liquid hydrogen, as reproduced in Annex 3 to this Regulation.

In the case of EX/II and EX/III vehicles the engine shall be of compression-ignition construction using only liquid fuels with a flashpoint above 55 °C. Gases shall not be used."

*Paragraph 5.1.3.4., renumber as paragraph 5.1.3.3.2.*

*Insert a new paragraph 5.1.3.4., to read:*

"5.1.3.4. Reserved"

*Paragraph 5.1.3.5., amend to read:*

"5.1.3.5. Electric power train

Electric power trains shall not be used for EX vehicles. Trailers with regenerative braking or electric power train are not allowed."

5.1.3.5.1. General provisions

The electric power train shall meet the requirements of UN Regulation No. 100, as amended at least by the 03 series of amendments.

Vehicles with an electric power train shall be equipped with an isolation resistance monitoring system.

The vehicle shall give external signals in stationary conditions, in addition to the warning to the driver received in the driver's cab as required by paragraph 6.15.1. of UN Regulation No.100 <sup>8</sup>, as amended at least by the 03 series of amendments.

5.1.3.5.2. Rechargeable Electrical Energy Storage System (REESS)

*Note:* Other acronyms for REESS are used in other documentation for similar systems (e.g. RESS).

REESS of vehicles with an electric power train shall be designed and constructed taking into account a risk evaluation according to ISO 6469-1:2019/Amd 1:2022 to establish safety for normal operational conditions.

A review shall be carried out by a technical service such as a technical service for vehicle approvals according to UN Regulation No. 100.

*Note:* Normal operating conditions also include malfunctions and reasonably foreseeable accidental situations.

5.1.3.5.3. Measures against thermal propagation

REESS containing cells for which thermal propagation cannot be guaranteed to be contained within the REESS, measures shall be taken to mitigate danger to the load by heating or ignition.

5.1.3.5.4. Vehicle charging inlet

The vehicle charging inlet shall be provided with thermal sensing function which limits or interrupts current transfer according to ISO 17409:2020, when the temperature exceeds component rated values or required limits by applicable product standards, see for example, IEC 62196-3-1:2020."

*Insert new paragraphs 5.1.3.7. to 5.1.3.7.3., to read (including the references to new footnotes <sup>9</sup> and <sup>10</sup>):*

"5.1.3.7. Hydrogen and fuel cell vehicles

5.1.3.7.1. Hydrogen fuel cell vehicles shall comply with the requirements for the electrical power train of paragraph 5.1.3.5.

5.1.3.7.2. Hydrogen fuel cell vehicles shall comply with UN Regulation No. 134<sup>9</sup>, as amended at least by the 02 series of amendments. Vehicles using liquid hydrogen shall be subject to the technical requirements as reproduced in Annex 3 to this Regulation.

5.1.3.7.3. Shut-off devices of hydrogen containers shall close automatically:

- (a) when the vehicle is no longer in driving mode;
- (b) at a deceleration of  $8.0 \text{ m} \cdot \text{s}^{-2}$  against the direction of travel; and

<sup>8</sup> UN Regulation No. 100 (Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train)

<sup>9</sup> UN Regulation No. 134 (Uniform Provisions concerning the Approval of Motor Vehicles and their Components with regard to the Safety-Related Performance of Hydrogen-Fuelled Vehicles (HFCV)).

(c) in case of a lateral overturning above an angle of 23°.

The shut-off devices may be re-opened by a deliberate action of the driver."

*Insert new paragraphs 10.5 to 10.6.5., to read:*

- "10.5. General transitional provisions
- 10.5.1. Contracting Parties applying this Regulation may grant type approvals according to any preceding series of amendments to this Regulation.
- 10.5.2. Contracting Parties applying this Regulation shall continue to grant extensions of existing approvals to any preceding series of amendments to this Regulation
- 10.6. Transitional provisions for the 07 series of amendments
- 10.6.1. As from the official date of entry into force of the 07 series of amendments, no Contracting Party applying this Regulation shall refuse to grant or refuse to accept type approvals under this Regulation as amended by the 07 series of amendments.
- 10.6.2. Transitional provisions for AT vehicles
- 10.6.2.1. Until 1 January 2027, Contracting Parties applying this Regulation shall accept type approvals to the preceding series of amendments, first issued before 1 January 2027.
- 10.6.2.2. As from 1 January 2027, Contracting Parties applying this Regulation shall not be obliged to accept type approvals issued to the preceding series of amendments to this Regulation."

Insert new annex 3, to read:

## "Annex 3

### Vehicles with a liquefied hydrogen storage system (LHSSs)

Paragraphs 1 to 6, RESERVED

#### 7.1. LHSS optional requirements

Annex XX. is organized as follows:

Para. 7.2. LHSS design qualification requirements

Para. 7.3. LHSS fuel system integrity

Para. 7.4. Test procedures for LHSS design qualification

Para. 7.5. Test procedures for LHSS fuel system integrity

#### 7.2. LHSS design qualification requirements

This Section specifies the requirements for the integrity of a liquefied hydrogen storage system.

The hydrogen storage system qualifies for the performance test requirements specified in this Section. All liquefied hydrogen storage systems produced for on-road vehicle service shall be capable of satisfying requirements of para. 7.2.

The manufacturer shall specify a maximum allowable working pressure (MAWP) for the inner container.

The test elements within these performance requirements are summarized in Table 124.

These criteria apply to qualification of storage systems for use in new vehicle production. They do not apply to re-qualification of any single produced system for use beyond its expected useful service or re-qualification after a potentially significant damaging event.

Table 14

#### Overview of the Performance Qualification Requirements

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Para. 7.2.1. Verification of baseline metrics

7.2.1.1. Proof pressure

7.2.1.2. Baseline initial burst pressure, performed on the inner container

7.2.1.3. Baseline Pressure cycle life

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Para. 7.2.2. Verification of expected on-road performance

Para. 7.2.2.1. Boil-off

Para. 7.2.2.2. Leak

Para. 7.2.2.3. Vacuum loss

Para. 7.2.3. Verification for service terminating performance: bonfire

Para. 7.2.4. Verification of components

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#### 7.2.1. Verification of baseline metrics

##### 7.2.1.1. Proof pressure

A system is pressurized to a pressure  $p_{\text{test}} \geq 1.3$  (MAWP  $\pm 0.1$  MPa) in accordance with test procedure para. 7.4.1.1. without visible deformation, degradation of container pressure, or detectable leakage.

##### 7.2.1.2. Baseline initial burst pressure

The burst test is performed per the test procedure in para. 7.4.1.2. 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  $R_p$  (minimum yield strength) is 1.0 for austenitic steels and  $R_p$  is 0.2 for other steels.

#### 7.2.1.3. 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 and EN 1251-2 and in all other countries an applicable regulation for the design of metallic pressure containers), or define and perform suitable tests (including para. 7.4.1.3.) 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 para. 7.4.1.3. testing, suitable tests shall be designed by the manufacturer to prove the same level of safety compared to a metallic container.

#### 7.2.2. Verification for expected on-road performance

##### 7.2.2.1. Boil-off

The boil-off test is performed on a liquefied hydrogen storage system equipped with all components as described in para. G.1.(b). of the preamble (Figure 36 in section G of Part I). The test is performed on a system filled with liquid hydrogen per the test procedure in para. 7.4.2.1. and shall demonstrate that the boil-off system limits the pressure in the inner storage container to below the maximum allowable working pressure.

##### 7.2.2.2. Leak

After the boil-off test in para. 7.2.2.1., the system is kept at boil-off pressure and the total discharge rate due to leakage shall be measured per the test procedure in para. 7.4.2.2.. The maximum allowable discharge from the hydrogen storage system is  $R \leq 150 \text{ NmL/min}$  where

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

##### 7.2.2.3. Vacuum loss

The vacuum loss test is performed on a liquefied hydrogen storage system equipped with all components as described in para. G.1.(b). and Figure 36 in Part I. The test is performed on a system filled with liquid hydrogen per the test procedure in para. 7.4.2.3. and shall demonstrate that both primary and secondary pressure relief devices limit the pressure to the values specified in para. 7.4.2.3. in case vacuum pressure is lost.

#### 7.2.3. Verification of service-terminating conditions: bonfire

At least one system shall demonstrate the working of the pressure relief devices and the absence of rupture under the following service-terminating conditions. Specifics of test procedures are provided in para. 7.4.3.



A hydrogen storage system is filled to half-full liquid level and exposed to fire in accordance with test procedure of para. 7.4.3. The pressure relief device(s) shall release the contained gas in a controlled manner without rupture.

For steel containers the test is passed when the requirements relating to the pressure limits for the pressure relief devices as described in para. 7.4.3. are fulfilled. For other container materials, an equivalent level of safety shall be demonstrated.

#### 7.2.4. Verification of components

The entire storage system does not have to be re-qualified (para. 7.2.) if container shut-off devices and pressure relief devices (components in Figure 36 in Part I excluding the storage container) are exchanged for equivalent components having comparable function, fittings, and dimensions, and qualified for performance using the same qualification (paras. 7.2.4.1. and 7.2.4.2.) as the original components.

##### 7.2.4.1. Pressure relief devices qualification requirements

Design qualification testing shall be conducted on finished pressure relief devices which are representative of normal production. The pressure relief devices shall meet the following performance qualification requirements:

- (a) Pressure test (para. 7.4.4.1. test procedure);
- (b) External leakage test (para. 7.4.4.2. test procedure);
- (c) Operational test (para. 7.4.4.4. test procedure);
- (d) Corrosion resistance test (para. 7.4.4.4. test procedure);
- (e) Temperature cycle test (para. 7.4.4.8. test procedure).

##### 7.2.4.2. Shut-off valves qualification requirements

Design qualification testing shall be conducted on finished shut-off valves (in Figure 36 in Part I named shut-off devices) which are representative for normal production. The valve shall meet the following performance qualification requirements:

- (a) Pressure test (para. 7.4.4.1. test procedure) ;
- (b) External leakage Test (para. 7.4.4.2. test procedure) ;
- (c) Endurance test (para. 7.4.4.3. test procedure) ;
- (d) Corrosion resistance test (para. 7.4.4.5. test procedure) ;
- (e) Resistance to dry-heat test (para. 7.4.4.6. test procedure) ;
- (f) Ozone ageing test (para. 7.4.4.7. test procedure) ;
- (g) Temperature cycle test (para. 7.4.4.8. test procedure) ;
- (h) Flex line cycle test (para. 7.4.4.9. test procedure).

#### 7.2.5. 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, Type of Fuel. Any label affixed to the container in compliance with this section shall remain in place. Contracting parties may specify additional labelling requirements.

#### 7.3. LHSS fuel system integrity

This section 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. These requirements are in addition to requirements specified in para. 5.2., all of which apply to vehicles

with liquefied hydrogen storage systems with the exception of para. 5.2.1.1. The fuelling receptacle label shall designate liquid hydrogen as the fuel type. Test procedures are given in para. 7.5.

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

7.3.2. 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.

7.4. Test procedures for LHSS design qualification

7.4.1. Verification tests for Baseline metrics

7.4.1.1. 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  $p_{\text{test}}$  is defined by the manufacturer and shall fulfil the following requirements:

$$p_{\text{test}} \geq 1.3 (\text{MAWP} \pm 0.1 \text{ MPa})$$

- (a) For metallic containers, either  $p_{\text{test}}$  is equal to or greater than the maximum pressure of the inner container during fault management (as determined in para. 7.4.2.3.) 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,  $p_{\text{test}}$  is equal to or greater than the maximum pressure of the inner container during fault management (as determined in para. 7.4.2.3.).

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  $p_{\text{test}}$  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.

7.4.1.2. 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 para. 7.2.1.2. 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.

#### 7.4.1.3. 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.

#### 7.4.2. Verification for expected on-road performance

##### 7.4.2.1. 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.

##### 7.4.2.2. Leak test

The test shall be is—conducted according to the procedure described in para. 7.4.4.2.

##### 7.4.2.3. 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 para. 7.4.2.1.);
- (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 para. 7.4.2.1.);
- (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.

#### 7.4.3. 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 para. 7.4.2.1.);

- (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 disk 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 disk is used inside the vacuum area as secondary pressure relief device, the pressure inside the container is limited to 150 per cent of the Maximum Allowable Working Pressure plus 0.1 MPa (MAWP  $\pm$  0.1 MPa) of the inner container.

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

#### 7.4.4. Component Verification Tests

Testing shall be performed with hydrogen gas having gas quality compliant with ISO 14687:2019/SAE J2719\_202003. All tests shall be performed at ambient temperature 20 ( $\pm$ 5) °C unless otherwise specified. The TPRD qualification performance tests are specified as follows:

##### 7.4.4.1. 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.

#### 7.4.4.2. 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 para. 7.4.4.3.3. 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/hour.

#### 7.4.4.3. Endurance test

7.4.4.3.1. A component shall be capable of conforming to the applicable leakage test requirements of paras. 7.4.4.2. and 7.4.4.9., after being subjected to 20,000 operation cycles.

7.4.4.3.2. The appropriate tests for external leakage and seat leakage, as described in paras. 7.4.4.2. and 7.4.4.9. shall be carried out immediately following the endurance test.

7.4.4.3.3. 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  $10 \pm 2$  seconds.

7.4.4.3.4. 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.

7.4.4.3.5. The component shall be operated through 2 per cent of the total cycles at the maximum material temperature ( $-40\text{ }^{\circ}\text{C}$  to  $+85\text{ }^{\circ}\text{C}$ ) after sufficient conditioning time at this temperature to ensure thermal stability and at MAWP. The component shall comply with paras. 7.4.4.2. and 7.4.4.9. at the appropriate maximum material temperature ( $-40\text{ }^{\circ}\text{C}$  to  $+85\text{ }^{\circ}\text{C}$ ) at the completion of the high temperature cycles.

7.4.4.3.6. The component shall be operated through 2 per cent of the total cycles at the minimum material temperature ( $-40\text{ }^{\circ}\text{C}$  to  $+85\text{ }^{\circ}\text{C}$ ) 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 paras. 7.4.4.2. and 7.4.4.9. at the appropriate minimum material temperature (-40 °C to +85 °C) at the completion of the low temperature cycles.

7.4.4.4. Operational test

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

7.4.4.5. Corrosion resistance test

Metallic hydrogen components shall comply with the leakage tests referred to paras. 7.4.4.2. and 7.4.4.9. after being submitted to 144 hours salt spray test according to ISO 9227 with all connections closed.

A copper or brass hydrogen containing component shall comply with the leakage tests referred to paras. 7.4.4.2. and 7.4.4.9. and after being submitted to 24 hours immersion in ammonia according to ISO 6957 with all connections closed.

7.4.4.6. Resistance to dry-heat test

The test shall be carried out in compliance with ISO 188. 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  $\pm 25$  per cent. The change in ultimate elongation shall not exceed the following values:

Maximum increase 10 per cent,

Maximum decrease 30 per cent.

7.4.4.7. Ozone ageing Test

The test shall be in compliance with ISO 1431-1. 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.

7.4.4.8. Temperature cycle test

A non-metallic part containing hydrogen shall comply with the leakage tests referred to in paras. 7.4.4.2. and 7.4.4.9. after having been submitted to a 96 hours temperature cycle from the minimum operating temperature up to the maximum operating temperature with a cycle time of 120 minutes, under MAWP.

7.4.4.9. Flex line cycle test

Any flexible fuel line shall be capable of conforming to the applicable leakage test requirements referred to in para. 7.4.4.2., 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 para. 7.4.4.2., shall be carried out immediately following the endurance test.

7.5. Test procedures for LHSS fuel system integrity

7.5.1. 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, and tests in para. 6.1.1. are to be performed; the following shall be installed before the test:

- (i) LHSS pressure sensor. The pressure sensor shall have a full scale of reading of at least 150 per cent of MAWP, an accuracy of at least 1 per cent of full scale, and capable of reading values of at least 10 kPa;
  - (ii) 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;
  - (iii) 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.
- (b) The LHSS is purged with at least 5 volumes of nitrogen gas;
  - (c) The LHSS is filled with nitrogen to the equivalence of the maximum fill level of hydrogen by weight;
  - (d) After fill, the (nitrogen) gas vent is to be closed, and the container allowed to equilibrate;
  - (e) 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, luggage, or cargo compartments during these post-crash tests.

Following confirmation that the pressure control and/or safety relief valves are still functional, a leak test shall be conducted on the LHSS using the procedures in either para. 6.1.1.1. or para. 6.1.1.2.

Either test procedure para. 7.5.1.1. or the alternative test procedure para. 7.5.1.2. (consisting of paras. 7.5.1.2.1. and 7.5.1.2.2.) may be undertaken to satisfy test procedure para. 7.5.1.

#### 7.5.1.1. Post-crash leak test for the liquefied hydrogen storage systems (LHSSs)

The following test would replace both the leak test in para. 7.5.1.2.1. and gas concentration measurements as defined in para. 7.5.1.2.2. 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 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.



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.

Prior to the leak test overpressure in the LHSS shall be released to atmospheric pressure and afterwards the LHSS shall 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.

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

Both tests of paras. 7.5.1.2.1. and 7.5.1.2.2. are conducted under the test procedure of para. 7.5.1.2.

##### 7.5.1.2.1. Alternative post-crash leak test

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 in para. 6.1.1.1. 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.

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.

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

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.

The LHSS shall then be filled with helium to 80 per cent of the MAWP of the container or to within 10 per cent 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 less than or equal to the following criterion based on the liquid capacity of the LHSS:

- (a) 2 atm allowable loss for 100L systems or less;
- (b) 1 atm allowable loss for systems greater than 100L and less than or equal to 200L; and
- (c) 0.5 atm allowable for systems greater than 200L.

##### 7.5.1.2.2. Post-crash enclosed spaces test

The measurements shall be recorded in the crash test that evaluates potential liquid hydrogen leakage in test procedure para. 7.5.1.2.1. if the LHSS contains hydrogen for the crash test or during the helium leak test in test procedure para. 6.1.2.

Select sensors to measure the build-up of hydrogen or helium (depending which gas is contained within the Liquefied Hydrogen Storage Systems (LHSSs) 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).

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

The installation in vehicles with LHSSs shall meet the same requirements as for vehicles with compressed hydrogen storage systems in para. 6.1.2. 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 points. The rolling average of each sensor shall be below the targeted criteria of 4 per cent hydrogen (for a test with liquefied hydrogen) or 0.8 per cent 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."

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