SGS-7-11
~~SGS-6-1~~

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~~August 11~~September 21, 2009

NOTE: section 5.1, storage system requirements was added – 8/3/2009

GLOBAL REGISTRY

Created on 18 November 2004, pursuant to Article 6 of the
AGREEMENT CONCERNING THE ESTABLISHING OF GLOBAL TECHNICAL REGULATIONS FOR WHEELED VEHICLES, EQUIPMENT AND PARTS WHICH CAN BE FITTED AND/OR BE USED ON WHEELED VEHICLES

(ECE/TRANS/132 and Corr.1)

Done at Geneva on 25 June 1998

Addendum

Global technical regulation No. xx

HYDROGEN POWERED VEHICLE
(Established in the Global Registry on [DATE])

Appendix

Proposal and report pursuant to Article 6, paragraph 6.3.7. of the Agreement

- Proposal to develop a global technical regulation concerning Hydrogen fuel cell vehicle (ECE/TRANS/WP.29/AC.3/17)
- Final progress report of the informal working group on Hydrogen fuel cell vehicle GTR .....

UNITED NATIONS

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A. STATEMENT OF TECHNICAL RATIONALE AND JUSTIFICATION

1. INTRODUCTION

1. In the ongoing debates over the need to identify new sources of energy and to reduce the emissions of green house gases, countries around the world have explored the use of various alternative gases as fuels, including compressed natural gas, liquefied propane gas, and hydrogen. Hydrogen has emerged as one of the most promising alternatives due to its virtual zero emission. In the late 1990's, the European Community allocated resources to study the issue under its European Integrated Hydrogen Project. A few years later, the United States outlined a vision for a global wide initiative, the International Partnership on the Hydrogen Economy, and invited Japan, European Union, China, Russia and many other countries to participate in this effort.

2. For decades scientists, researchers and economists have pointed to hydrogen, in both compressed gaseous and liquid forms, as a possible candidate as an alternative to gasoline and diesel as vehicle fuel. Ensuring the safe use of hydrogen as fuel is a critical ingredient in the world economies successfully transitioning to a hydrogen economy. By their nature, all fuels present an inherent degree of danger due to their energy content. The safe use of hydrogen, particularly in the compress gaseous form, lies in preventing catastrophic failures due to volatile combination of fuel, ambient air and ignition sources.

3. The governments have identified development of regulations and standards as one of the key requirements for a long-term promotion in commercialization of hydrogen-powered vehicles. Regulations and standards will help overcome technological barriers to commercialization, facilitate manufacturers' investment in building hydrogen-powered vehicles and facilitate public acceptance by providing a systematic and accurate means of assessing and communicating risk associated with the use of hydrogen vehicles, be it to the general public, consumer, emergency response personnel and the insurance industry.

4. The goals of this global regulation (GTR) are to develop and establish a GTR for Hydrogen Fuel Cell Vehicles (HFCV) that: (1) Attains equivalent levels of safety as those for conventional gasoline powered vehicles and (2) Is performance-based and does not restrict future technologies.

2. GTR ACTION PLAN

5. Given that hydrogen-powered vehicle technology is still emerging, WP.29/AC.3 agreed that input from researchers is a vital component of this effort. Based on a comparison of existing regulations and standards of HFCV with conventional vehicles, it is important to investigate and consider: (1) The main differences in safety and environmental aspects and (2) What items need to be regulated based on justification.

6. In June 2005, WP.29/AC.3 agreed to a proposal from Germany, Japan and United States of America regarding how best to manage the development process for a GTR on hydrogen-powered vehicles (ECE/TRANS/WP.29/AC.3/17). Under the agreed process, once AC.3 develops and approves an action plan for the development of a GTR, two subgroups will be formed to address the safety and the environment aspects of the GTR. The subgroup safety (HFCV-SGS) will report to GRSP. The chair for the group will be discussed and designated by summer of 2007. The environmental subgroup (HFCV-SGE) is chaired by European Commission and reports to GRPE. In order to ensure communication between the subgroups and continuous engagement with WP.29 and AC.3, the project manager (Germany) will coordinate and manage the various aspects of the work ensuring that the agreed action plan is implemented properly and that milestones and timelines are set and met throughout the development of the GTR. The GTR will cover fuel cell (FC) and internal combustion engine (ICE), compressed gaseous hydrogen (CGH2) and liquid hydrogen (LH2) in the phase 1 GTR. At the (X) WP.29, the GTR action plan was submitted and approved by AC.3 (ECE/TRANS/WP.29/2007/41).

7. In order to develop the GTR in the context of an evolving hydrogen technology, the trilateral group proposes to develop the GTR in two phases:

(a) Phase 1 (GTR for hydrogen-powered vehicles):
Establish a GTR by 2010 for hydrogen-powered vehicles based on a component level, subsystems, and whole vehicle crash test approach. For the crash testing, the GTR would specify that each contracting party will use its existing national crash tests but develop and agree on maximum allowable level of hydrogen leakage. The new Japanese regulation, and any available research and test data will be used as a basis for the development of this first phase of the GTR.

(b) phase 2 (Assess future technologies and harmonize crash tests):
Amend the GTR to maintain its relevance with new findings based on new research and the state of the technology beyond phase 1. Discuss how to harmonize crash test requirements for HFCV regarding whole vehicle crash testing for fuel system integrity.

8. The GTR will consist of the following key areas:

(a) Component and subsystem level requirements (non-crash test based):
Evaluate the non-crash requirements by reviewing analyses and evaluations conducted to justify the requirements. Add and subtract requirements or amend test procedures as necessary based on existing evaluations or on quick evaluations that could be conducted by Contracting Parties and participants. Avoid design specific requirements to the extent possible and do not include provisions that are not justified. The main areas of focus are as follows:

(i) Performance requirements for fuel containers, pressure relieve devices, fuel cells, fuel lines, etc.
(ii) Electrical isolation; safety and protection against electric shock (in-use).
(iii) Performance and other requirements for sub-systems integration in the vehicle.

(b) Whole vehicle requirements (crash test based):
Examine the risks posed by the different types of fuel systems in different crash modes, using as a starting point the attached tables. Review and evaluate analyses and crash tests conducted to examine the risks and identify countermeasures for hydrogen-powered vehicles. The main areas of focus are as follows:

(i) Existing crash tests (front, side and rear) already applied in all jurisdictions.
(ii) Electrical isolation; safety and protection against electric shock (post crash).
(iii) Maximum allowable hydrogen leakage.

9. Application: the contracting parties decided at this to set requirements for passenger FC vehicles only with the understanding that in the coming years, it will appropriate to extend the application of the regulation and/or establish new requirements for additional classes of vehicles, specifically, motor coaches, trucks, and two-/three-wheel motorcycles.]

3. DESCRIPTION OF COMPRESSED HYDROGEN FUEL CELL VEHICLES

1. Hydrogen fuel cell vehicles (FCVs) have an electric drive-train powered by a fuel cell that generates electric power electrochemically from hydrogen. In general, FCVs are equipped with other advanced technologies to increase efficiency, such as regenerative braking systems that capture the energy lost during braking and store it in a battery or ultra-capacitors. While the various FCVs are likely to differ with regard to details of the systems and hardware/software implementations, the following major systems are common to most FCVs:

A. Hydrogen fueling system
B. Hydrogen storage system
C. Hydrogen fuel delivery system
D. Fuel cell system
E. Electric propulsion and power management system

2. A high-level schematic depicting the functional interactions of the major systems is shown in Figure 1. Hydrogen is supplied to the fill port on the vehicle and flows to the hydrogen storage container(s) within the Hydrogen Storage System. The hydrogen supplied to and stored within the hydrogen storage container can be either compressed gas or liquefied hydrogen. When the vehicle is started, the shut-off valve is opened and hydrogen gas is allowed to flow from the Hydrogen Storage System. Pressure regulators and other equipment with the Hydrogen Delivery System reduce the pressure for use by the fuel cell system The hydrogen is electro-chemically combined with oxygen (from air) in the Fuel Cell System, and high-voltage electric power is produced by the fuel cells. The power from the fuel cells flows to the Electric Propulsion and Power Management System where it is used to power drive motors and/or charge batteries and ultra-capacitors, depending on the driver "throttle" and brake positions and the operating state of the vehicle.

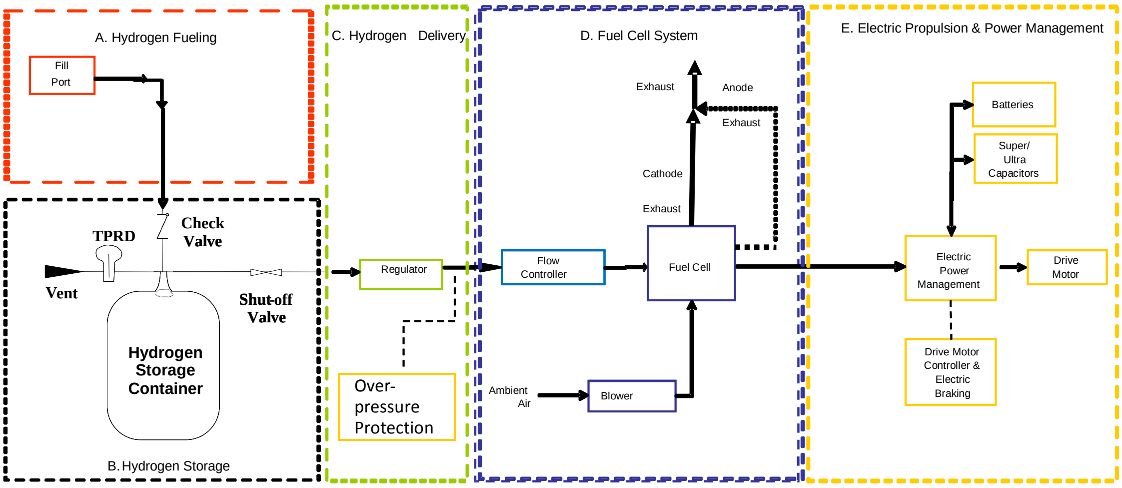


Figure 1. High-level Schematic of Key Systems in FCVs

3. Figure 2 illustrates key components in the major systems of a typical fuel cell vehicle (FCV). The fill port is shown in a typical position on the rear quarter panel of the vehicle. As with gasoline tanks, hydrogen storage containers, whether compressed gas or liquefied hydrogen, are usually mounted transversely in the rear of the vehicle. Fuel cells and ancillaries are usually located (as shown) under the passenger compartment or in the traditional “engine compartment”, along with the power management, drive motor controller, and drive motors. Given the size and weight of traction batteries and ultra-capacitors, these components are usually located in available space in the vehicle in areas that retain proper desired weight balance for proper handling of the vehicle.

4. More detailed descriptions of the major systems are provided in the following sections.

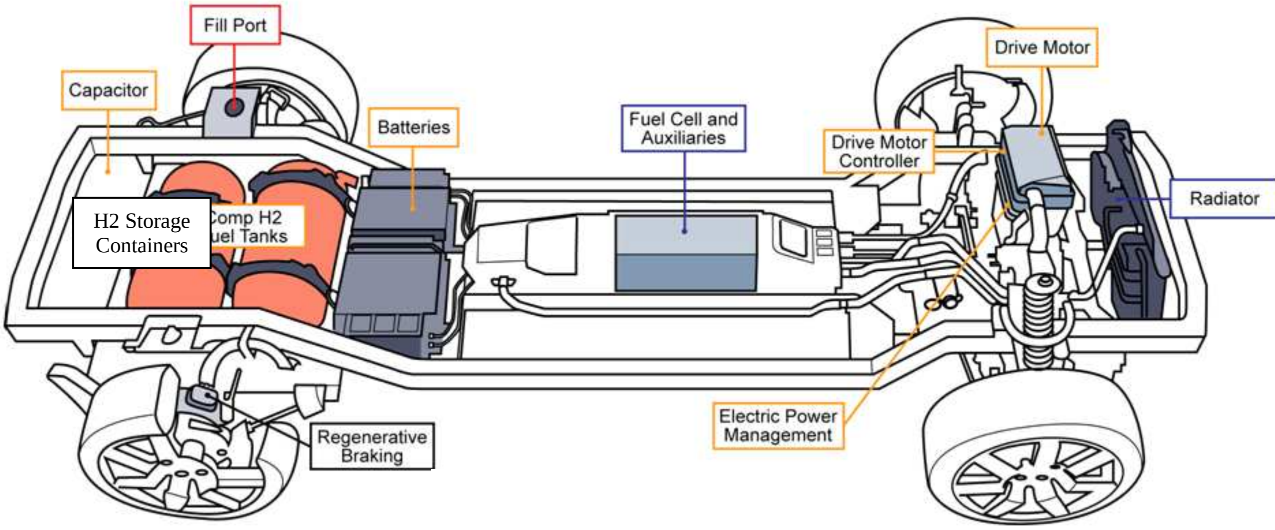


Figure 2. ~~Illustration of Typical~~Sample of a ~~-~~Fuel Cell Vehicle (for illustration only)

3.1 HYDROGEN FUELING SYSTEM

5. Either liquefied or compressed gas may be supplied to the vehicle, depending on the type of hydrogen storage used by the vehicle. At present, the most common method of storing and delivering hydrogen fuel onboard is in compressed gas form where the hydrogen is dispensed at pressures up to 87.5 MPa (12,5000 psi) to over-come the effects of compression adiabatic heating during “fast fill” of containers rated for a nominal working pressure (NWP) of 70 MPa (10,000psi).

6. Regardless of state of the hydrogen, the vehicles are fuelled through a special nozzle on the filling stations to the fill port on the vehicle which allows a “closed system” transfer of hydrogen to the vehicle such that people in the dispensing area are not exposed to unacceptable hazards. The fill port on the vehicle also contains a check valve (or other device) that prevents leakage of hydrogen out of the fill port in the event of a fault of the back-flow prevention in the hydrogen storage system

7. In addition to the above features on the vehicle, the dispenser also contains safe-guards to monitor the fueling process and ensure that the temperature and pressure are consistent with the capability of the hydrogen storage system on the vehicle.

3.2 HYDROGEN STORAGE SYSTEM

8. The hydrogen storage system consists of all components that form the primary pressure boundary of the stored hydrogen gas in the system. The primary function of the hydrogen storage system is to contain the hydrogen within the storage system throughout the vehicle life.

9. At present, the most common method of storing and delivering hydrogen fuel on-board is in compressed gas form. Hydrogen can also be stored as liquid (at cryogenic conditions). Each of these types of hydrogen storage systems are described in the following sections.

3.2.1 COMPRESSED HYDROGEN STORAGE SYSTEM

10 . Components of a typical compressed hydrogen storage system are shown in Figure 3. The system includes the container and all other components that form the “primary pressure boundary” that prevents hydrogen from escaping the system. In this case, the following components are part of the compressed hydrogen storage system:

a) the container(s),
b) the fill line check valve,
c) the shut-off valve,

d) the thermally-activated pressure relief device (TPRD),
and
e) the interconnecting piping (if any) and fittings between the above components.

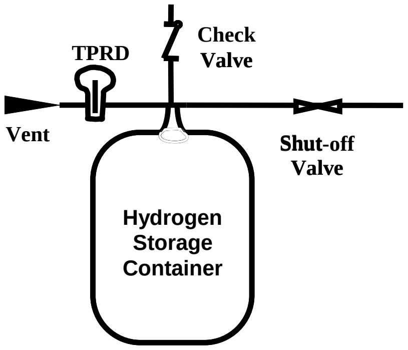


Figure 3. Typical Compressed Hydrogen Storage System

11. The hydrogen storage containers store the compressed hydrogen gas. A hydrogen storage system may contain more than one container based on the amount that needs to be stored and the physical constraints of the particular vehicle. Hydrogen fuel has a low energy density per unit volume. To overcome this limitation, compressed hydrogen storage containers store the hydrogen at very high pressures. On current development vehicles, hydrogen is typically stored at a nominal working pressure of 35 MPa (5,000 psi) or at 70 MPa (10,000 psi). During the normal “fast fill” fueling process, the actual pressure inside the container(s) may rise to 25% above the nominal working pressure as adiabatic compression of the gas will cause a short-term pressure rise in the tanks. After approximately one (1) hour, the temperature in the container will cool to near ambient and the pressure will reduce. By definition, the settled pressure of the system will be equal to the nominal working pressure when the tank is at 15 degC.

12. Containers are currently constructed with composite materials in order to meet the challenge of high pressure containment of hydrogen at a weight is that is acceptable for vehicular applications. Most high pressure hydrogen storage containers being evaluated in fuel cell development vehicles consist of multi-layers with an inner liner made of aluminum or thermoplastic polymer to prevent gas leakage/permeation and a resin-impregnated carbon fiber composite that is wrapped over a gas sealing inner for structural integrity.

13. During fueling, hydrogen enters the system from the hydrogen fueling system through a check valve (or shut-off valve). The check valve prevents back-flow (leakage) of hydrogen out through the hydrogen fueling line (after fueling is complete and the fueling nozzle has been disconnected).

14. The hydrogen shut-off valve prevents the out-flow of stored hydrogen when the vehicle is not operating or when a fault is detected that requires isolation of the hydrogen from down-stream systems or the enviroment.

15. In the event of a fire, thermally-activated pressure relief devices (TPRDs) vent (i.e., provide a controlled release of) the gas contained in compressed hydrogen storage containers before the high temperatures in a fire degrade composite and metal container materials and consequently cause a hazardous rupture of the hydrogen storage containers. Storage containers and TPRDs that have been subjected to a fire should be removed from service and destroyed; hence, the TPRDs are designed to vent the entire contents of the container rapidly and do not reseat or allow re-pressurization of the container.

OICA / GS will provide modifications to the description of the fuel cell vehicle for clarification.

Germany: change to SI units

3.2.1 LIQUEFIED HYDROGEN STORAGE SYSTEM (put in separate section)

16. As noted previously, hydrogen gas has a low energy density per unit volume. To overcome this disadvantage, the liquefied hydrogen storage system (LHSS) maintains the hydrogen at a very low temperature in a liquefied state.

17. A typical liquefied hydrogen storage system (LHSS) is shown in the unshaded area of Figure 4. Actual systems will differ in the type, number, configuration, and arrangement of the functional constituents. For example, in some systems the hydrogen evaporator (heat exchanger) is integrated into the storage container rather than located in the downstream hydrogen system. Ultimately, the boundaries of the LHSS are defined by the interfaces which can isolate the stored liquefied (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 section while components outside the boundary are subject to general requirements in Section 4. For example, the typical liquefied LHSS shown in Figure 4 consists of the following components:

a) the fill line check valve,
b) liquefied hydrogen storage container(s),
c) shut off devices(s),
d) Pressure Relief Valves (PRVs),
e) the interconnecting piping (if any) and fittings between the above components.

18. During fueling, liquefied hydrogen flows from the fuelling system to the storage container(s). A check valve (or shut-off valve) is located on the fill line to prevent back-flow when fuelling is complete.

19. Liquefied hydrogen is stored at cryogenic conditions. In order to maintain the hydrogen in the liquid state, the container needs to be well insulated, including use of a vacuum jacket that surrounds the storage container. Pressure regulators (PRVs) and pressure

relief valves (PSVs) protect both the hydrogen storage container(s) and the vacuum the jacket(s) surrounding the storage container(s) from over-pressure due to heat transfer from ambient or during external fires.

20. When hydrogen is released to the propulsion system, it flows from the LHSS through the shutoff valve. The hydrogen flow from the storage container may be single or two phase flow, depending on the location of the hydrogen evaporator (the heat exchanger that vaporizes any liquefied hydrogen flowing out of the storage container). In the event that a fault is detected in the propulsion system, vehicle safety systems usually require the container shutoff valve to isolate the hydrogen from the down-stream systems and the environment.

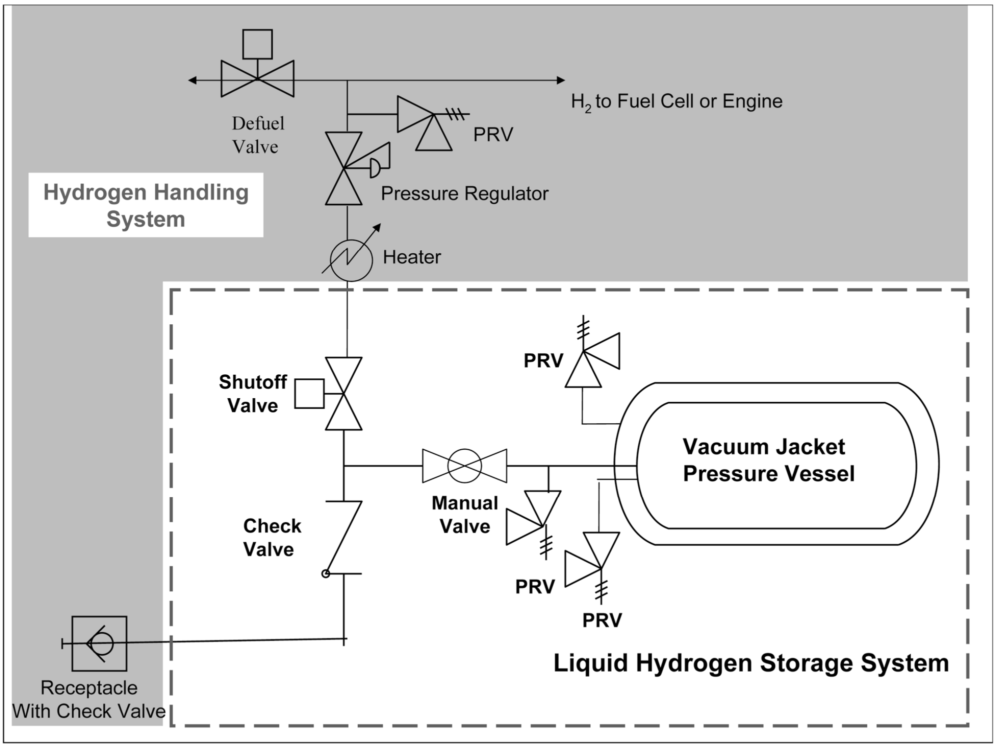


Figure 4. Typical Liquefied Hydrogen Storage System

3.3 HYDROGEN FUEL DELIVERY SYSTEM

21. Hydrogen is delivered from the storage containers to the fuel cell stack via a series of pressure regulators, control valves, filters, piping, and possibly heat exchangers and heaters. The fundamental purpose of a hydrogen flow control system is to reliably deliver fuel to the fuel cell stack at a specified pressure and temperature for proper fuel cell operation over the full range of vehicle operating conditions.

22. The fuel system delivery system must reduce the pressure from levels in the hydrogen storage system to values required by the fuel cell system. In the case of 70 MPa compressed hydrogen storage system, the pressure may have to reduced from as high as 87.5 MPa

(12,5000 psi) to levels typically under 1MPa at the inlet of the fuel cell system. This challenge requires multiple stages of pressure regulation to achieve accurate and stable control and over-pressure protection of down-stream equipment in the event that a fault in the regulation system occurs. Over-pressure protection may be accomplished by either venting excess hydrogen gas through pressure safety valves or isolating the hydrogen gas supply (by closing the shut-off valve) in the hydrogen storage system when an over-pressure condition is detected.

~~5.2~~• ISO-member recommendation (slide 4): Do not refer to 70MPa as an upper limit; write document for unlimited pressure.
Discussion: this is the only reference to 70MPa; it is not written/intended as a limitation. “70MPa (10000 psi)” can be replaced by “NWP”.

3.4 FUEL CELL SYSTEM

23. The fuel cell generates the electricity needed to operate the drive motors and charge vehicle batteries and/or capacitors. There are several kinds of fuel cells, but Proton Exchange Membrane (PEM) fuel cells are the common type used in automobiles at this time. The PEM fuel cells electro-chemically combine hydrogen and oxygen (in air) to generate electrical DC power. Fuel cells are capable of continuous electrical generation when supplied with hydrogen and oxygen (air), simultaneously generating electricity and water without producing carbon dioxide (CO_2) or other harmful emissions typical of gasoline-powered internal combustion engines (ICE).

24. As shown in Figure 1, typical fuel cell systems include a blower to feed air to the cathode-side of the fuel cells. Approximately 50 to 70% of the oxygen is consumed within the cells. The remainder is exhausted from the system. The fuel cell usually consumes most of the hydrogen that is supplied, but a small excess is required to ensure that the fuel cells will not be damaged. The excess hydrogen is either mixed with the cathode exhaust to produce a non-flammable exhaust from the vehicle or catalytically reacted.

25. The fuel cell system also includes auxiliary components and systems to remove the waste heat. Most fuel cell systems are cooled by a mixture of gylcol-water. Coolant pumps circulate the water through the fuel cells and then to radiator.

26. The individual fuel cells are usually “stacked” or electrically connected in series such that the power is between 300 and 600 Vdc. Since fuel cells operate a high voltage, all reactant and coolant connections (including the coolant itself) to the fuel cell need to be adequately isolated from the conductive chassis of the vehicle such that there are no shorts that could cause equipment damage or harm people when insulation is breeched.

3.5 ELECTRIC PROPULSION AND POWER MANAGEMENT SYSTEM

27. The electric power generated by the fuel cell is ultimately used to drive electric motors that ultimately propel the vehicle. As illustrated in Figure 2, many passenger fuel cell vehicles are front wheel drive with the electric drive motor and drive-train located in the “engine compartment” mounted transversely over the front axle. Larger SUV-type fuel cell

vehicles may be all wheel drive with electric motors on the front and rear axles or with compact motors at each wheel.

28. The “throttle position” is used by the drive motor controller(s) to determine that the amount of power to be sent to the drive wheels. Many fuel cell vehicles use batteries or ultra-capacitors to supplement the output of the fuel cells. These fuel cell vehicles may also recapture energy during stopping through regenerative braking to re-charge the batteries or ultra-capacitors and thereby maximize efficiency.

29. The drive motors may be either DC or AC. If the drive motors are AC, the drive motor controller must convert the DC power from the fuel cells, batteries, and ultra-capacitors to AC. Conversely, if the vehicle has regenerative braking, the drive motor controller must convert the generated in the drive motor back to DC so that the energy can be stored in the batteries or ultra-capacitors.

4. EXISTING REGULATIONS, DIRECTIVES, AND INTERNATIONAL VOLUNTARY STANDARDS

4.1 VEHICLE FUEL SYSTEM INTEGRITY

National regulations:

- ~~5.3~~EC regulation 79-2009
- Japanese Safety Regulation article 17 and Attachment 17 – Technical Standard for Fuel Leakage in Collision, etc.
- Japanese Attachment 100 – Technical Standard For Fuel Systems Of Motor Vehicle Fuel By Compressed Hydrogen Gas
- ECE
- United States Federal Motor Vehicle Safety Standard (FMVSS) No. 301 - Fuel System Integrity.
- Canadian Motor Vehicle Safety Standards (CMVSS) 301.2 – Fuel System Integrity
- Korea Motor Vehicle Safety Standard, Article 91 – Fuel System Integrity

Industry standards:

- ISO
- SAE J2578 - Recommended Practice For General Fuel Cell Vehicle Safety

4.2 STORAGE-SYSTEM

National regulations:

- Japanese (add Japan’s 35 Mpa regulation)
- ECE
- FMVSS 304 - Compressed Natural Gas fuel Container Integrity.
- Korea High Pressure Gas Safety Control Law

Industry standards:

- ISO

- SAE J2579 - Technical Information Report for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles

4.3 ELECTRIC SAFETY

National regulations:

- Japanese Attachment 101 – Technical Standard for Protection of Occupants against High Voltage in Fuel Cell Vehicle.
- ECE Regulation 100 - Uniform Provisions Concerning The Approval Of Battery Electric Vehicles With Regard To Specific Requirements for The Construction AND Functional Safety
- FMVSS 305 - Electric-Powered Vehicles: Electrolyte Spillage and Electrical Shock Protection.
- CMVSS 305—Electric Powered Vehicles: Electrolyte Spillage And Electrical Shock Protection
- Korea Motor Vehicle Safety Standard, Article 18-2 – High Voltage System
- Korea Motor Vehicle Safety Standard, Article 91-4 – Electrolyte Spillage and Electric Shock Protection

Industry standards:
ISO to provide info. On ISO stds

- ISO
- SAE J1766—Recommended Practice for Electric and Hybrid Electric Vehicle Battery Systems Crash Integrity Testing

5. TECHNICAL RATIONALE

5.1 STORAGE-SYSTEM

Explain the current requirements on CGN fuel container. Existing regulations and

Describe current standards on H2 container. (North America, Japan, and Europe)

Explain the differences between CNG and H2 container (higher pressure, etc.)

RATIONALE FOR REQUIREMENTS IN PART B 5.1

This section specifies the rationale for the requirements established in part B for the integrity of the compressed hydrogen storage system.

5.1 The storage system is defined to include all closure surfaces that provide primary containment of high pressure hydrogen storage. The definition provides for future advances in design, materials and constructions that are expected to provide improvements in weight, volume, conformability and other attributes.

5.1.2 Performance-based requirements, therefore, address all known on-road stress factors and usages to assure robust qualification for suitability for vehicle service.

5.1.2.2.2 The verification test for expected on-road performance requires the demonstration of capability to perform essential safety functions under worst-case conditions of expected exposures. “Expected” exposures (for a typical vehicle) include the fuel (hydrogen gas), environmental conditions (such as often encountered temperature extremes), and normal usage conditions (such as expected vehicle lifetime range, driving range per full fill, fueling conditions and frequency, and parking). Expected service requires sequential exposure to parking and fueling stresses since all vehicles encounter both uses and the capability to survive their cummulative impact is required for the safe performance of all vehicles in expected service.

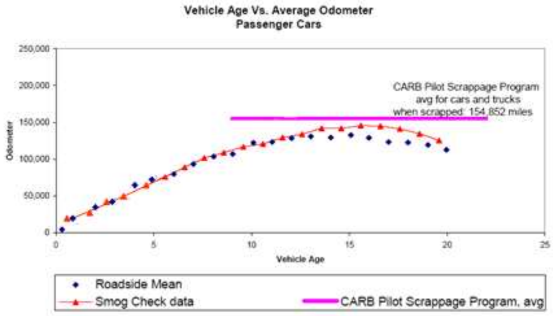
Add the actual 25 years as the purpose of the test.

Data bases for 5.1.2.2.2 test protocol include:

1. Proof Pressure Test – routine production of pressure vessels includes a verifying, or proof, pressure test at the point of production, which is 150% as industry practice.
2. Typical temperature extremes -- weather records (any UN member government) show temperatures ≤ -40C occur in countries north of the 45-th parallel; temperatures ~50C occur in desert areas of lower latitude countries.
3. Expected Service: worst-case = lifetime of most stressful fuelings (empty-to-full fuelings) under expected (typical) usage; 15 years at full-fill parking; ~~one~~ and 10 service-station over-pressurization events.

Need rationale for 15 years limitation. 15 years is currently in the Japanese regulation.

4. Number of fueling/de-fueling cycles
    - i. Expected vehicle lifetime range is taken to be 155k mi (250k km)



Source: Sierra Research Report No. SR2004-09-04, titled "Review of the August 2004 Proposed CARB Regulations to Control Greenhouse Gas Emissions from Motor Vehicles: Cost Effectiveness for the Vehicle Owner or Operator", and dated September 22, 2004.

    - ii. Expected vehicle range per full fueling is taken to be 300 mi (483km) based on 2006-2007 market survey of Nissan, Daimler, Chrysler, General Motors, Ford, Honda, and Toyota products.
    - iii. Therefore, the expected number of full fuelings in the worst-case (only full fuelings in vehicle lifetime) is taken to be 500 ~ 155 000/300.
    - iv. Since the stress of full fuelings exceeds the stress of partial fuelings, the design verification test provides a significant margin of additional robustness.
    - v. On-road experience: 70MPa hydrogen storage systems have failed (leakage) during brief on-road service of demonstration prototype vehicles.

    vi. Test experience: 70MPa hydrogen storage systems that passed NGV2 test requirements have failed during the 5.1.2.2.2 test conditions in failure modes that would be expected to occur in on-road service (Powertech report to DOE/SAE).

5. Fueling conditions

    ~~vii.~~i. SAE J2601 establishes fueling protocol -- 3 minutes is fastest full fueling; fuel temperature for fast fueling is ~ -40C.

    ~~viii.~~ii. Expected maximum thermal shock conditions are system equilibrated at ambient temperature ~50C subjected to -40C fuel, and system equilibrated at -40C subjected to indoor private fueling at ~20C.

6. Parking at full fill for 15 years

    ~~ix.~~i. On-road experience with CNG tanks -- no stress rupture without exposure to corrosives (stress corrosion cracking).

    ~~x.~~ii. Laboratory experience with high pressure vessel composite strands – documentation of time-to-rupture as a function of static stress (Aerospace Corp Report No. ATR-92(2743)-1 (1991) and references therein) without exposure to corrosives

    ~~xi.~~iii. Use of laboratory data to define equivalence of test failure probability for testing at 100% NWP for 15 years and testing at 125% NWP for 1000 hours is documented in SAE 2009-01-0012.

    ~~xii.~~iv. No formal data on parking duration per vehicle at different fill conditions. Examples of expected lengthy full fill occurrences include vehicles maintained at near full fill at all times, abandoned vehicles and collectors' vehicles.

7. Leak/permeation

    ~~xiii.~~i. Leak and permeation are risk factors for fire hazards in confined spaces such as parking garages.

    ~~xiv.~~ii. The leak/permeation limit is defined to protect the worst-case condition of a tight (30m3) warm (55°C) garage having low air exchange (0.03 volumetric air exchanges per hour) from reaching 25% LFL. The 25% margin is conventionally adopted to accommodate concentration inhomogeneities.

    ~~xv.~~iii. Data reference for garage sizes, air exchange rates, and garage temperatures are found in the EU HySafe report “Allowable Hydrogen Permeation Rate for Automotive Applications” VTEC Doc No. 06120-09-13603-1, 2009.

    ~~xvi.~~iv. A localized leak test is to be conducted to ensure that external leakage cannot sustain a flame that could weaken materials and subsequently cause loss of containment. Per SAE 2008-01-0726 *Flame Quenching Limits of Hydrogen Leaks*, the lowest flow of H2 that can support a flame is 0.028 mg/sec per from a typical compression fitting and the lowest leak possible from a miniature burner configuration is 0.005 mg/sec. Since the miniature burner configuration is considered a conservative “worst case”, the maximum leakage criteria is selected as 0.005 mg/sec.

    ~~xvii.~~v. Fueling Station Over-pressurization (5.1.2.2.2.5).

    ~~xviii.~~vi. Fueling station over-pressurization constrained by fueling station requirements to ≤ 150% NWP

    ~~xix.~~vii. Laboratory data on static stress rupture used to define equivalent probability of stress rupture of composite strands after 30 seconds at 180% NWP as after 2 hours at 150% NWP in the worst case (SAE 2009-01-0012).

    ~~xx.~~viii. Field data on the frequency of failures of high pressure fueling stations involving activation of pressure relief controls is not available. The small number of 70MPa fueling stations currently available does not support robust statistics.

8. Residual Strength Burst (5.1.2.2.2.6)
   Requirement for <20% decline in burst pressure after 1000-hr static pressure exposure is linked (in SAE 2009-01-0012) to assurance that requirement has allowance for 10% manufacturing variability in assurance of > 15 years of rupture resistance at 100% NWP.

5.1.2.2.1 The verification test for on-road performance durability ensures the system is fully capable of avoiding rupture under extreme conditions of usage that include extensive fueling frequency (perhaps associated with replacement of drivetrain components), physical assaults and harsh environmental conditions. These durability tests focus on structural durability needed to prevent rupture. The addition attention to rupture resistance under harsh external conditions is provided because 1) the severity of consequences from rupture is high, 2) rupture is not mitigated by secondary factors – leak is mitigated by onboard leak detection linked to countermeasures. Since these extreme conditions are focused on structural fatigue, they are conducted hydraulically – which allows more extensive stress exposure in practical time. [Pneumatic testing provides additional stress factors focused on the vessel interior and strongly linked to initiation of leakage.]

Data bases for 5.1.2.2.1 test protocol include:

1. Extended & Severe Service worst-case = lifetime of most stressful fuelings (empty-to-full fuelings) under extended & severe usage; 10 service-station over-pressurization events
2. Number of fueling/de-fueling cycles in extended usage
   i. A higher than expected number of fuelings occurs if: 1) the vehicle lifetime mileage is higher than expected, 2) the vehicle range per full fill is lower than expected, 3) the average vehicle fueling is less than a full fill.
   ii. The high-frequency extreme number of partial fuelings is given by: (extreme-usage lifetime vehicle range) / (minimal vehicle range per full fill) / (minimal lifetime average fill volume fraction).
   iii. The minimal lifetime average fill volume fraction is taken as 0.33. Reliable statistics on current fill volume fraction are not available; statistics for hydrogen-fueled vehicles will be influenced by the availability of hydrogen fueling stations. The qualification test specification is based on the assumption that a lifetime of fuelings needing <33% of fuel capacity provides a high-frequency extreme associated with a lifetime average of fuelings on intervals of 70 – 100 miles traveled.
   iv. Extreme-usage lifetime vehicle range is taken as 366,000 miles (590 km). Sierra Research Report No. SR2004-09-04 for the California Air Resource Board (2004) on vehicle lifetime mileage showed all scrapped vehicles had mileage below 350 k miles (the 3-sigma value, the 99.8th percentile, was 260k miles; the 6-sigma value was 366 k miles).
   v. Minimal vehicle range per full fill is taken as 200 mi (322 km). At present all on-road vehicles produced by high volume vehicle manufacturers have a vehicle range per full fill greater than 300 miles.
   vi. Therefore, the extreme number of fuelings is taken as 5500 = 3 x 366,000/200.
   vii. Robustness (safety margin) of extended durability design-qualification requirement
      ~~f)~~o The probability of a system encountering the specified number of fuelings is the product: Prob$_1$(vehicle range ≥366 000 miles) x Prob$_2$(vehicle full-fill range ≤200 miles) x Prob$_3$(vehicle lifetime average fueling volume ≤33%). Estimates

from data cited above indicate $Prob_1$ and $Prob_2$ are each lower than 1/million, ensuring the result is below 10^{-12}.

~~g)~~o A vehicle with a modest driving range of 200 miles per full fueling would have to be driven over 1 million miles to require 5500 empty-to-full fuelings.

~~h)~~o Low-volume partial fills cause markedly lower swings in temperature and pressure, and consequently markedly lower stresses than empty-to-full fill stresses. Comprehensive data is not available (stresses an order of magnitude lower than empty-to-full fuelings have been seen). Therefore, conducting the high-frequency fueling pressure cycle tests with empty-to-full fueling pressure swings provides a margin of robustness potentially on the order of x 10.

3. Severe usage: Exposure to chemicals in the on-road environment
   - i. Fluids include fluids used on vehicles (battery acid & washer fluid), chemicals used on or near roadways (fertilizer nitrates & lye), and fluids used in fueling stations (methanol in gasoline).
   - ii. The primary historical cause of rupture of high pressure vehicle vessels (CNG tanks), other than fire, has been stress corrosion rupture – rupture occurring after a combination of exposure to corrosive chemicals and pressurization.
   - iii. Stress corrosion rupture of on-road glass-composite wrapped vessels exposed to battery acid was replicated by the proposed test protocol; other chemicals were added to the test protocol once the generic risk of chemical exposure was recognized.
   - iv. Penetration of coatings from impacts and expected on-road wear can degrade function of protective coatings -- recognized as a contributing risk factor for stress corrosion cracking (rupture); capability to manage that risk is therefore required.
4. Severe usage: Exposure to physical impacts
   - ~~a.~~i. Roadway impacts that degrade exterior structural strength and/or penetrate protective coatings (e.g., flying stone chips) – administered by pendulum impact
   - ~~b.~~ii. Surface damage – cuts characteristic of wear from mounting straps can wear through protective coatings – administered cuts representative of strap wear
   - ~~c.~~iii. Drop impact – risk is primary aftermarket risk in vehicle repair where a new storage system, or an older system removed during vehicle service, is dropped from a fork lift during handling. The test procedure requires drops from several angles from a maximum utility forklift height. The test is designed to demonstrate that containment vessels have the capability to survive representative pre-installation drop impacts if the system does not have unalterable markers that record exposure to comparable impacts to designate that installation is not authorized.
5. Sequential performance of tests replaces on-road experience where a single vessel is subject to multiple exposures – not realistic to expect a vessel could only encounter one type of exposure through vehicle life.

5.1.2.3 Performance Tests Requirements for Criteria-Qualified Systems

~~□~~1. All production units are required to have full capability to comply with 5.1.2.2 but may formally qualify for on-road service using simplified testing under specific criteria:
   - ~~□~~i. Systems constructed (liner and/or body) with stainless steel SUS316L or aluminum A6061 (Japan will supply rationale)
   - ~~□~~ii. New systems that are very similar to previously qualified systems –criteria for being sufficiently similar are specified based on NGV history.
   - ~~□~~iii. Alternative tests are hydraulic stressors of rupture-inducing fatigue to confirm resistance to the biggest risk impact, which is rupture. Pneumatic tests primarily

stress the vessel interiors and lead to leak, which is secondarily mitigated by onboard leak detection; hence, less of a risk considering the lesser severity of impact, secondary mitigation and previous qualification of a similar system (or metal leak-resistant interior).

5.1.2.4 Verification of performance under service terminating conditions is designed to prevent the severe impact of rupture under condions so severe that hydrogen containment cannot be maintained.

1. Engulfing bonfire test is tradition fire safety test – primary objective is to ensure presence of a TPRD.
2. Penetration test -- no direct correspondence to crash safety. However, in some locales local officials express concern about risk from exposure to gunfire – the test is reassuring to those officials, though actually not realistic given the extreme caliber and marksmanship required to perform the test.

Japan requests for technical rationale for penetration/bullet impact test.

5.1.2.1 and 5.1.3 Verification of Baseline Metrics and Documentation of Production Quality Control

1. Performance verification testing of one (or few) systems is only meaningful if production units correspond to the units tested. Establishing of key metrics of units tested for performance is required for documentation of correspondence of manufacturing units.
2. Nominal (average) initial burst strength is required to be > 2.0 x NWP -- this allows 10% manufacturing variability with all units > 1.8 x NWP.
3. Nominal (average) pressure cycle life is required to be > minimum number of test cycles in 5.1.2.2.1 and is set to highest value measured during performance testing if variability is high (>25%) to assure that tested units are not stronger than manufactured units. For vessels that do not leak after 11000 cycles, pressure cycle life is set to 11000. (The constraint for ≤25% variability is immediately satisfied when pressure cycle life is set to 11000).

Add section for liquefied hydrogen storage system; This section specifies the rationale for the requirements established in part B for the integrity of the liquefied hydrogen storage system.

5.1.3 Storage System Production Requirements

Manufacturers are expected to ensure that all production units meet the requirements of performance verification testing in 5.1.2. Manufacturers of storage systems must provide the following information to regulatory authorities upon request.

5.1.3.1 Documentation of Routine Production (Each Produced Unit). Documentation should include results of routine leak tests, proof pressure tests, and dimension, and NDE examinations verifying that expansion and flaw sizes are within design specifications. Documentation should show that components providing closure functions, such as the shut-off valve, check valve and the TPRD meet industry standards.

5.1.3.2 Documentation of Periodic Production Tests (Batch/Lot Tests). Documentation should include measurements and statistical analyses used to confirm that

a) the average (hydraulic) initial burst pressure of new storage containers is > BP_0 (established in 5.1.2.2.4.1) and that the initial burst pressure of every produced unit is > 180% NWP and > 90% BP_0.

b) the average (hydraulic) pressure cycle life of new storage containers is > PCL_0 (established in 5.1.2.2.4.2) and that the pressure cycle life of every produced unit is > 75% PCL_0 and > 5500.

5.2. VEHICLE FUEL SYSTEM

5.2.1 IN-USE

Below are the requirements from the TUV proposal that were recommended for Part A; rewrite the language for part A:

Provide an explanation why the SGS decided to move these proposed requirements to part A.

- The hydrogen system of a vehicle shall function in a safe and proper manner. It shall reliably withstand the chemical, electrical, mechanical and thermal service conditions

- The materials used in the hydrogen system shall be compatible with gaseous or liquid hydrogen.

- A hydrogen system shall fulfil at least the following functions:
  − refuelling
  − protection against overpressure;
  − excess flow protection
  − automatic shut-off (automatic isolation of the fuel storage system)
  − safety management
  − boil-off management for LH2

- No component of the hydrogen system, including any protective materials that form part of such components, shall project beyond the outline of the vehicle or protective structure. *Need to explain why this is not required in the part B of the GTR. Or how it would be covered by the system safety requirements.*

- The hydrogen system shall be installed such that it is protected against damage under normal operating conditions.

- An excess flow system for the fuel line and the filling line shall be part of the hydrogen system

- A pressure relief device shall be provided and installed into the opening of a container or at least one container in a container assembly, or into an opening in a valve assembled into the container. *This issue is being addressed by the storage system's bonfire test. Provide explanation in Part A.* **Contracting party may clarify requirements for acceptable operation of PRD such as CSA…or ISO…., for the purpose of type approval.**

GS will provide a write-up on PRD, its operation, possible failures and the need of compliance to certain industry standards.

Japan will provide a risk assessment to justify all three following components for each container: main shut off valve, a container check valve (=container non-return valve) and a container safety valve (= pressure relief device).

Container assembly = Storage system; storage container = tank or vessel without valves

- Rigid fuel lines shall be secured such that they shall not be subjected to critical vibration or other stresses, e.g. they shall be supported at an interval of 1 m or less.. *Justification for not accepting the Japanese requirement shall be provided in part A.*

Also, recommended practices can be mentioned as part of the write-up.

- During the refilling process the hydrogen system shall have the means to provide electrical continuity with the refilling facilities before hydrogen transfer is permitted. *Japan will provide test data for justification in part A.*

- The receptacle shall be secured against maladjustment and rotation. The receptacle shall also be protected from unauthorized interference, and the ingress of dirt and water so far as is reasonably practicable, e.g. a locked hatch. It shall be safe against reasonably foreseeable handling errors. *provide a write-up on for part A. Encourage industry to standardize filling receptacle.*

- The gas filling port (or receptacle make sure it's consistent thru out the document)- shall not be installed in the passenger compartment, luggage compartment and other places where ventilation is not sufficient. *provide write up for part A.*

[Need explanations and justifications including test reports, analysis, studies for:

- 4% lower flammability limit (LFL)]

Lower Flammability Limit (LFL): Lowest concentration of fuel in which a gas mixture is flammable. National and international standard bodies (such as NFPA and IEC) recognize 4% hydrogen in air as the LFL. See the US Department of Interior, Bureau of Mines Report 503 for further information. Flammability limits (LFL, UFL) depend on mixture temperature, pressure and the presence of dilution gases, and are assessed using specific test methods (e.g., ASTM E681-04). While the LFL value in Note a is appropriate for evaluating flammability in general surroundings of vehicles or inside passenger compartments, this criteria may be overly restrictive for flowing gas situations where ignition requires more than

4% hydrogen in many cases. Whether an ignition source at a given location can ignite the leaking gas plume depends on the flow conditions and the type of ignition. At 4% hydrogen in a stagnant, room temperature mixture, combustion can only propagate in the upward direction. At approximately 8 to 10% hydrogen in the mixture, combustion can also be propagated in the downward and horizontal directions and the mixture is readily combustible regardless of location of ignition source. Insert NHTSA test report on fire hazard study.

Insert rationale for warning system: Amber for detection system malfunction and Red for hydrogen leakage - Martin

xy. Telltale/Driver Warning

Germany will provide a more detailed rationale for warning requirement.

[If a single failure of the hydrogen system results in a hydrogen concentration in air greater than 4% by volume within the passenger compartment, luggage compartment, and spaces within the vehicle that contain unprotected ignition sources, the main hydrogen shutoff valve(s) shall close and provide warning.

Protection against flammable conditions of 4% by volume hydrogen in air (or greater) in the passenger compartment, luggage compartment, and spaces is important. Vehicles may achieve this objective by design (for example, where spaces are vented to prevent increasing hydrogen concentrations) or other means. If the vehicle is designed to detect hydrogen concentrations of 4%, then the main hydrogen shutoff valve(s) shall close to prevent further increases and provide for dissipation of the hydrogen, and the driver shall be provided with a warning through a visual telltale so the driver can anticipate the change in vehicle operation.]

The safety of occupants is of utmost concern to the SGS experts. In recognition that the most dangerous situations can occur in case of unintended leakage of hydrogen potentially reaching critical concentration levels. It has been agreed that in order to prevent catastrophic failures, the on-board hydrogen container should be equipped with a shut off valve that is automatically activated in cases of failure of the hydrogen storage system and unintended leakage of hydrogen.

OICA requests for better text to accurately reflect the requirement in 5.2.1.2

The SGS agreed unanimously that the GTR should include a provision requiring a telltale/warning system that would alert the driver in case of ~~the automatic shut-off of~~ hydrogen leakage that results in concentration levels ~~of four percent and~~ higher *than 4% by volume within the passenger compartment, luggage compartment, and spaces within the vehicle*. The SGS also agreed that the telltale should alert the driver in case of a malfunction of the detection system itself.

The GTR requires that the system shall be able to detect either scenario and instantly warn the driver. The shut-off telltale shall be inside the occupant compartment in front of and in clear view of the driver. The group discussed also whether it is necessary to make the telltale warning visual only or in case of the shut-off, add an audible warning. There is no data to suggest that the warning function of the telltale would be diminished if it is only visual so for the time being the group did not add the requirement that the warning should be audible as well. It is up the manufacturer to decide whether they would like to add this feature.

When starting the vehicle, the hydrogen system malfunction telltale shall be briefly activated

The telltale should stay illuminated until the cause, which triggered the telltale warning to go off, is eliminated. When illuminated, the telltale shall be sufficiently bright to be visible to the driver under both daylight and night time driving conditions.

CAUSES	SYMBOL	CONTROL	COLOUR
Detection system malfuncation	TBD	TELL-TALE	YELLOW
Hydrogen leakage	TBD	TELL-TALE	RED

xy Telltale Color Requirement

The SGS agreed that the two scenarios for the warning to go off should be differentiated so that the driver and occupants can make appropriate decisions. It was agreed that the color of the light for the system working correctly (“On/Run”) should be green. Manufacturers are permitted to use the telltale in a steady or flashing mode to indicate normal operation of the system.

xy Malfunction of the detection system warning

In case of the detection system failure, the telltale warning light should be amber/orange. In case of the emergency shut-off of the valve, the telltale light should be red. The group believed that differentiating between the two scenarios will clearly communicate to the driver exactly which condition is occurring and facilitate better decisions by the driver. . In the context of the hydrogen system telltale, the amber/yellow warning would be “cautionary”, communicating properly to the driver the level of urgency with which the driver shall seek to remedy the malfunction of this important safety feature. Specifically, in case of the detection system malfunction it shall not be necessary to stop and abandon the vehicle. It was discussed in the group that in such case, the driver would continue driving to the destination or place, where it would be reasonable to expect that somebody would be able to inspected and service the vehicle

xy Emergency hydrogen valve shut-off warning

In cases where the hydrogen leak results in a concentration level in air of four percent or higher, the pressure relief valve shall be immediately activated to shut off the flow of hydrogen from the storage container. The shut-off of the valve should trigger an immediate red color warning issued to the driver. In such case, the driver should immediately proceed to park and shut down the vehicle.

xy Telltale labeling

While the group agreed on the need for the hydrogen detection system malfunction and the hydrogen container shut-off telltale, there was no consensus among the participants as to what symbol should be used for the telltale; how it should be identified.

In terms of labeling the hydrogen system malfunction telltale, it was discussed labeling the telltale with a letter "H", the international symbol for hydrogen from the Periodic Table of Elements. It is also the letter "H" that that the Japanese manufacturers chose as symbol for the hydrogen system telltales in their vehicles. SGS, however, after considering comments from all stakeholders, including the industry, did not stipulate what symbol to use at this point.

xy Telltale location

The SGS is leaving the location of the telltale up to the manufacturers in recognizing that stipulating a specific location would not increase or decrease safety of the hydrogen vehicle. It is also anticipated that manufacturers would like to have the discretion whether to place such warning on the panel or heads up display. Instead, SGS members believe it is sufficient to stipulate that the telltale shall be in the direct and clear view of the driver while in the driver's designated seating position with the driver's seat belt fastened ensuring that manufacturers will choose a reasonable location for the telltale. The group, therefore, does not anticipate that the manufacturer would place the telltale in a less prominent location such as the vehicle's central console, for example.

Insert rationale for TPRD discharge directions

Insert rationale for exhaust H2 discharge limit
Description of the fuel cell's operation and its discharge of diluted fuel; and exhaust system's operation including figures…
Explain the 3-second moving interval

Include GS's calculation

Insert rationale for [not] regulating the secondary pressure system (downstream of the pressure regulator)

5.2.2 POST CRASH requirements:

Insert explanation for contracting parties maintaining their existing crash tests in phase 1.

Explain the heat calculation from gasoline to hydrogen. Explain the different between the Japanese limit and OICA limit. (check Japan's presentation submitted in SGS-5)

Insert explanation for crash test leakage limit and monitoring time

Insert explanation for alternative fuel for crash test

5.2.3

5.3. ELECTRIC SAFETY

Describe the Japanese regulation;

Other government regulations

Industry standards

B. TEXT OF REGULATION

1. Purpose: This regulation specifies performance requirements for hydrogen-powered vehicles. The purpose of this regulation is to minimize human harms that may occur as a result of fires or explosions related to the vehicle fuel system and/or from electric shock caused by the vehicle's high voltage system.

2. Application / Scope: This regulation applies to all vehicles of Category 1-1 and 1-2, with a gross vehicle mass (GVM) of 4,536 kilograms or less.

3. Definitions

For the purpose of this regulation, the following definitions shall apply: Hydrogen powered vehicle: any motor vehicle that uses hydrogen as fuel to propel the vehicle including fuel cell and internal combustion engine vehicle.

3.1 Vehicle fuel system: all components used to store or supply hydrogen fuel to the storage system or to the fuel cell module or internal combustion engine (ICE).

3.2 Storage system: The Hydrogen Storage System consists of the pressurized container(s), Pressure Relief Devices (PRDs), shut off device(s), and all components, fittings and fuel lines between the container(s) and these shut off device(s) that isolate the stored hydrogen from the remainder of the fuel system and the environment.

3.3 Pressure relief device (PRD): A device that, when activated under specified performance conditions, is used to release fluid from a pressurized system and thereby prevent failure of the system. Thermally activated PRDs are designated TPRDs.

3.4 Pressure relief valve: A pressure relief device that opens at a preset pressure level and can re-close.

3.5 Single failure: a failure caused by a single event, including any consequential failures resulting from this failure.

3.6 Fuel cell module: Fuel cell modules are comprised of one or more fuel cell stacks; connections for conducting fuels, oxidants, and exhausts; electrical connections for the power delivered by the stacks; and means for monitoring and/or control. Additionally, fuel cell modules may incorporate means for conducting additional fluids (e.g., cooling media, inert gas), means for detecting normal and/or abnormal operating conditions, enclosures or pressure vessels, and ventilation systems.

3.7 Lower Flammability limit (LFL): Lowest concentration of fuel at which a gaseous fuel mixture is flammable at normal temperature and pressure.

3.8 UFL: Highest concentration of fuel at which there is sufficient oxidant in the gas mixture for the mixture to be flammable. The UFL of hydrogen is 74% in air. Remove if not used in section 5.

3.9 The exhaust's point of discharge: geometric center of the area where fuel cell purged gas is discharged from the vehicle.

3.10 High voltage: Classification of an electric component or circuit, if its maximum working voltage is > 60 V and ≤ [1500] V of direct current (DC) or > 30 V and ≤ [1000] V of alternate current AC.

3.11 High voltage: High voltage is defined as greater than or equal to 60 VDC and 30 VAC. Refer to ELSA document

3.12 [Enclosed and semi-enclosed space: Volume surrounded by vehicle components or structure in such a manner that hydrogen may accumulate within the volume. These volumes include, but are not limited to, spaces such as passenger compartment, luggage compartment, fuel storage compartment, and space under the hood.(and spaces under the vehicle)]

4. General requirements:

4.1 Each hydrogen-powered vehicle shall meet the requirements of section 5.1 and 5.2. In addition, vehicles using high voltage shall meet the requirement of section 5.3.

4.2 Each contracting party under the UNECE 1998 Agreement will maintain its existing national crash tests and use the limit values of section 5.1.3.1 for compliance.

5. Performance requirements

The following, section, 5.1, contains OICA's proposal for the storage system and relevant comments from ISO and from the discussions of SGS-5 meeting. This section is kept in square brackets and subjected to discussion and agreement.

5. Performance requirements

5.1 [Hydrogen Storage system:

~~6~~• Chair Comment: As a result of consensus at the Budapest and Mainz meetings, the OICA proposal is accepted as the working draft for the storage requirements for this GTR.

~~7~~• Comments from other SGS members are included.

- Question: should container's NWP be limited by 70 Mpa?
- Japan regulation sets upper limit at 70 Mpa.

The upper limit of NWP shall not be lower than 70 MPa.
Members will submit rationale to support setting upper limit or not.

This section specifies the requirements for the integrity of the compressed hydrogen storage system. The hydrogen storage system consists of the high pressure storage container(s) and closures of openings into the high pressure storage container(s). Closures include the temperature-activated pressure relief device(s) (TPRD), check valve(s), shut-off valve(s) and all components, fittings and fuel lines between the storage container(s) and the closure device(s) that isolate high pressure hydrogen from the remainder of the fuel system and the environment. A check valve prevents reverse flow in the vehicle fill line. A shut-off valve between the storage container and the vehicle fuel system defaults to the closed position when unpowered.

GS - Need definitions for storage components: temperature-activated pressure relief device(s) (TPRD), check valve(s), shut-off valve(s)

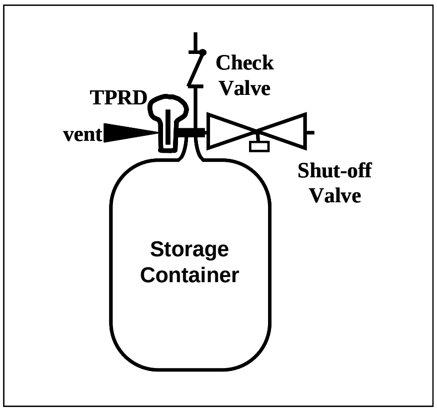


Figure 5.1.1 Generic Hydrogen Storage System

- ISO-member recommendation (slide 3): **Types of tanks**: Keep the types 1, 2, 3 and 4 to avoid performing tests that may not be necessary on some types of tanks.

  SGS-6 Discussion: This limits designs (material/construction) to current manufacturers capabilities; type 1, 2, 3 and 4 [metal tanks, hoop-wrapped and full-wrapped tanks; carbon & glass wrap material; aluminum & steel liners]. Current technologies have limited applicability due to cost, weight, mass and lack of conformability. Opportunity for competitive high volume deployment is linked to technology advancement. The benefit of performance-based requirements is 1) the ability of new technologies to qualify without delay of regulatory revision often linked to professional consent of disadvantaged competitors, 2) performance-based requirements are not dependent on full knowledge of failure modes, but rather knowledge of applicable on-road stress factors.

Qualification requirements for on-road service include:
5.1.1 Material Requirements
5.1.2 Storage System Performance Test Requirements
5.1.3 Storage System Production Requirements
The test elements within these performance requirements are summarized in Table 5.1.

Table 5.1.1
Overview of Performance Qualification Test Requirements

<table>
<tr><th colspan="2">5.1.1 Material Requirements</th></tr>
<tr><th colspan="2">5.1.2 Storage System Performance Test Requirements</th></tr>
<tr><th colspan="2">5.1.2.1 Verification Tests for Baseline Metrics</th></tr>
<tr><td colspan="2">5.1.2.1.1 Baseline Initial Burst Pressure
5.1.2.1.2 Baseline Initial Pressure Cycle Life</td></tr>
<tr><td>5.1.2.2 Performance Test Requirements for New Systems</td><td>5.1.2.3 Performance Test Requirements for Criteria-Qualified Systems</td></tr>
<tr><td>5.1.2.2.1 Verification Test for Performance Durability (sequential hydraulic tests)</td><td>5.1.2.3.2 Expected Service and Durability Performance Test (sequential hydraulic tests)</td></tr>
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5.1.2.2.1.1 Proof Pressure Test 5.1.2.2.1.2 Drop (Impact) Test 5.1.2.2.1.3 Surface damage and Chemical Exposure Test 5.1.2.2.1.4 Extreme Fueling Usage; Ambient Temperature Pressure Cycling Test 5.1.2.2.1.5 Residual Proof Pressure Test 5.1.2.2.1.6 Residual Strength Burst Test	5.1.2.3.2.1 Hydraulic Proof Pressure Test 5.1.2.3.2.2 Drop (Impact) Test 5.1.2.3.2.3 Surface damage and Chemical Exposure Test 5.1.2.3.2.4 Extreme Fueling Usage: Ambient Temperature Pressure Cycling Test 5.1.2.3.2.5 Parking Performance Verification Test: Extreme Temperature Static Pressure Test (hydraulic) 5.1.2.3.2.6 Extreme Fueling Conditions; Extreme Temperature Pressure Cycling Test. (hydraulic) 5.1.2.3.2.7 Residual Proof Pressure Test 5.1.2.3.2.8 Residual Strength Burst Test
5.1.2.2.2 Verification Test for Expected On-road Performance (sequential pneumatic tests) 5.1.2.2.2.1 Proof Pressure Test 5.1.2.2.2.2 Fueling Performance Verification Test: Extreme Temperature Pressure Cycling Test (pneumatic) 5.1.2.2.2.3 Parking Performance Verification Test: Extreme Temperature Static Pressure Test (pneumatic) 5.1.2.2.2.4 Leak/Permeation Test 5.1.2.2.2.5 Residual Proof Pressure Test 5.1.2.2.2.6 Residual Strength Burst Test (Hydraulic)	**5.1.2.3.3 Permeation Test**
5.1.2.4 Verification Test for Fail-Safe Performance	
5.1.2.4.1 Engulfing Fire (Bonfire) Test	
5.1.2.4.2 Penetration Test	
5.1.3 Storage System Production Requirements	

Pneumatic tests

- US Comment: Production quality control should not be part of the GTR, could be part of additional requirements e.g. in the type approval system
- EC - Study reservation on COP.

Discussion clarification: requirement is record keeping for production, not production qualification testing. Assurance of conformity of production is required so that test sample(s) are representative of expected on-road service capability.

- ISO – are these tests defined in the proposal? Section 5.1.3

5.1.2.1 Material Requirements

[Manufacturers are expected to assure that materials used in storage systems meet design specifications of the manufacturer and are capable of enduring on-road conditions and the performance verification testing in 5.1.2. Manufacturers of storage systems must maintain information relevant to the system design that includes:

a) tensile properties and softening temperature (>100C) of plastic liner material
b) glass transition temperature
c) resin shear strength
d) coating adhesion and flexibility]

- Link the tests to procedures in 6.4.1
- ISO-member recommendation (slide 12): Since material properties are essential requirements for the safety of containers, we recommend that they be incorporated in the GTR text.
- Japan proposes to add a hydrogen embrittlement test once the requirements/procedures are finalized.

SGS-6 Discussion: Provision for material properties may be appropriate. Provisions within SAE TIR J2579, ISO TS 15869, EIHP, and NGV2 are similar in content.

US – Material requirements are not necessary since we have an overall performance-based qualification. Keep in part B and ~~Move this to Part A~~explain in part A that this requirement is for type approval.]

5.1.~~2~~2 Storage System Performance Test Requirements

Definitions of the used terms have to be included!

The hydrogen storage system will be qualified to the performance test requirements specified in 5.1.2.2 and 5.1.2.4, or requirements specified in 5.1.2.3 and 5.1.2.4. All new vehicle hydrogen storage systems must be capable of satisfying requirements of 5.1.2.2. The test requirements in 5.1.2.3 provides a simpler means to qualify those storage systems that meet the criteria specified in 5.1.2.3.1. The specifications for all test procedures in 5.1.2.2 and 5.1.2.3 are provided in Section 6.

- ~~*(Comment: OICA will provide additional information for the justification of this option and for the material tests.*~~
- ~~*US Comment: the systems must be tested for formal certification, but for self certification locales the requirement for potential enforcement on all new production remains with the requirement that all new units have full capability.*~~

The storage system does not have to be re-qualified if the subsystem components are exchanged for components with comparable function, fittings, and dimensions, and meet comparable component performance qualification specifications. A change in the TPRD hardware, its position of installation and/or venting lines requires re-qualification with a bonfire test.

This criteria applies to qualification of storage systems for use in new vehicle production. It does 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.

5.1.2.1 Verification Tests for Baseline Metrics

5.1.2.1.1 Baseline Initial Burst Pressure Test: At least 3 new storage containers will undergo a hydraulic burst test to verify that the initial burst pressure of each container is $\geq$ 180% NWP and to determine BP_0, the average value, as the baseline initial burst pressure for 5.1.3.2. To accommodate at least 10% manufacturing variability, BP_0 must be $\geq$ 200% NWP.

- ISO-member recommendation (slides 9&10): use historical CNG initial burst requirements.
  SGS-6 Discussion: 1) The basis for the CNG initial burst requirements is mixed. The glass requirement was based on static fatigue strand (cured resin-impregnated fibers) data – the same data supports equivalent safety (equivalent probability of rupture) for glass composite strands through the requirement for no rupture in 1000hr at 125% (See SAE 2009-01-0012). The CNG value for carbon composites exceeds the value suggested by strand data (SAE 2009-01-0012); the difference being linked to subjective and competitive business factors. The value for metal is linked to the final trial reduction ordered during WWII.
  2) The historical CNG initial burst requirements were established based on estimated fatigue resulting in loss of burst strength over vehicle life – based on static fatigue data – while the draft GTR requires that extreme fatigue stresses beyond those possible in vehicle life be directly replicated to ensure resulting fatigue is realistically evaluated. Thus the draft GTR substitutes the more severe end-of-life testing for beginning-of-life testing and, in addition, retains completely the linkage to the strand fatigue data (1000hr @125%NWP) that was the basis of the orginal CNG initial burst requirements.
  3) the historical CNG burst requirements anticipate/accommodate substantial (> factor of 3) deterioration in burst strength over vehicle life. The draft GTR requires much greater structural stability by requiring that burst strength may deteriorate by less than 1/5 (20%) over exposure to a lifetime of cyclic and static stress
  4) 40 yrs of experience with CNG does not translate to 40 years of experience with hydrogen and 70MPa pressure; much of the safety improvement with CNG came from the requirement for pressure cycling after chemical exposure, reduced corrosive stress rupture, the primary cause of failures other than fire. The draft GTR proposal retains requirements for pressure cycling after chemical exposure. The advantage of performance-based testing is that it does not require knowledge of all failure modes, but rather replication of extreme on-road conditions. Knowledge of how the time factor affects failure modes -- as used to develop initial burst pressure requirements for lower-pressure CNG – is accommodated fully accommodated in the draft GTR..
  5) As the pressure increases, the margin in strength associated with a multiplicative NWP factor is magnified well beyond accommodation for presumably additive associated stresses and results in compliance burden without associated realizable safety benefit.
  6) Variability due to manufacturing is explicitly accommodated in the draft GTR requirements (SAE 2009-01-0012 and presentation at 2009 SAE Global Congress) that limits manufacturing variability in initial burst pressure to 10% and accommodates that

10% in assurance of lifetime (25 years) resistance to static stress-induced rupture and a lifetime of cycling stress-induced rupture, combined.

- ~~ISO member recommendation (slide 11): include historical stress ratio requirements in consideration of vessels with load-bearing liners.~~

  ~~*SGS-6 Discussion: Performance requirements apply to all vessels, including those with load bearing liners, and thereby require demonstration of all vessels to perform under lifetime stresses.*~~
- *Post the PowerTech test report on website.*

- ~~ISO member recommendation (slide 19): a hydrostatic burst test should be included in the GTR~~

  ~~*SGS-6 Discussion: the draft has a hydrostatic burst test.*~~

5.1.2.1.2 Baseline Pressure Cycle Life (Leak Before Break) Test. At least 3 new storage containers will undergo ambient hydraulic pressure cycling from <2MPa to 150%NWP without rupture for 11,000 cycles (2 times the number of cycles required for 5.1.2.2.1.4) or until leak occurs. The pressure cycle life, PCL, of a storage container is the number of cycles until leak. If no leak occurs, then PCL is equated to 11,000. All 3 storage containers must have a pressure cycle life, PCL, within 25% of PCL_0. PCL_0, the average of the measured PCLs, is the baseline pressure cycle life for 5.1.3.2.

- ~~Comment by TUV: To provide some statistic information it is required to cycle 2 tanks pneumatically and hydraulically if this test (5.2.2.3.4) is deleted from the draft~~Question on the number of representative samples? Germany will make a proposal for amendment.

5.1.2.2 Performance Test Requirements for New Systems

All new hydrogen storage systems must be capable of satisfying the test requirements of sections 5.1.2.2.1, 5.1.2.2.2 and 5.1.2.2.3. The performance test requirements consist of:

5.1.2.2.1 Verification Test for Performance Durability (Hydraulic sequential tests)
5.1.2.2.2 Verification Test for Expected On-road Performance (Pneumatic sequential tests)
5.1.2.2.3 Verification Test for Fail-Safe Performance

5.1.2.2.1 Verification Test for Performance Durability (Hydraulic sequential tests)

A hydrogen storage system must not leak during the following sequence of tests, which are illustrated in Figure 5.1.2.2.1 ~~5.1.3~~. At least one system must be tested to demonstrate the performance capability. Specifics of applicable test procedures for the hydrogen storage system are provided in Section 6.

- *How many containers have been tested in this requirement? Provide PowerTech report.*

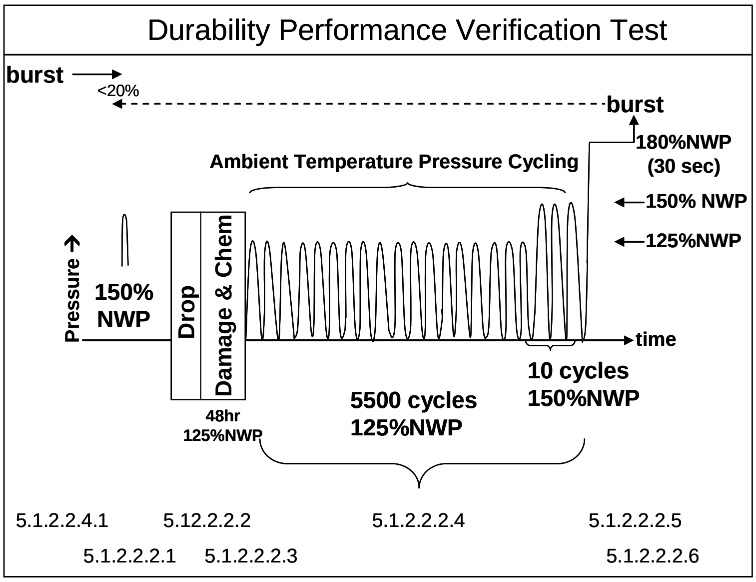


Figure 5.1.2.2.1 Verification Test for Performance Durability

5.1.2.2.1.1 Hydraulic Proof Pressure Test. A system will be pressurized to 150%NWP.

5.1.2.2.1.2 Drop (Impact) Test. The storage container will be dropped at several impact angles. All drop tests may be performed on one storage container, or individual impacts on a maximum of 3 containers. Following the drop impact, the storage container(s) will be subjected to 1000 pressure cycles. The containment vessel subjected to the 45^{o} angle drop will undergo further testing as specified in the remainder of 5.1.2.2.2, which includes the required 1000 pressure cycles.

US comments: Include a schematic in the test procedure to show the drop angles.

5.1.2.2.1.3 Surface damage and Chemical Exposure Test: The storage container will be subjected to surface damage and exposed to chemicals typical of worst-case on-road exposures. After 48 hours of exposure without leak, the container will be inspected to verify no further damage.

5.1.2.2.1.4 ~~5.1.2.2.1.4 —~~Extreme Fueling Usage; Ambient Temperature Pressure Cycling Test. The storage container will not leak or give visual evidence of deterioration when pressure cycled (repeatedly filled to 125% NWP and defueled to <2MPa) at 15 – 25^{o}C ambient temperature. The number of pressure cycles will be 5500.. Chemical exposures are maintained throughout the first 1000 pressure cycles. The last 10 cycles are to 150% NWP.

- Japan proposes using extreme temperatures in place of ambient temperatures.

- ISO-member recommendation (slide 6): ISO and SAE specify 11500 cycles for commercial applications.

  SGS-6 Discussion: The extra durability for commercial applications is to accommodate heavy duty commercial applications, such as buses, that conventionally accumulate greater mileage do to replacement of engines and transmissions during the chassis life. The UNGTR applies only to light-duty vehicles that conventionally accumulate mileage associated with a single drivetrain. The provision of 5500 cycles accommodates 1.7 million miles (2.7 million km) of driving @ 300 miles (480 km) per full fill. This accommodates light-duty commercial applications such as taxis that refuel to full fills repeatedly throughout vehicle life because that usage is limited by lifetime vehicle mileage.
  - EC expresses reservation on this issue in light of taxi.

- ISO-member recommendation (slide 7): For systems qualified with 5500 cycles, a counter or marking should be required to ensure that excessive stressful (full fill) fueling does not occur.

  SGS-6 Discussion: requiring a counter to restrict fueling is equivalent to requiring an odometer to limit mileage to less than a million miles – an unnecessary requirement for the light-duty scope of this UNGTR. IWG does not support the use of counter. Wait for EC investigation for resolution.

- ISO-member recommendation (slide18): may not need a separate Leak-Before-Break (LBB) test since the cycling tests serve a similar function.

  SGS-6 Discussion: ~~recommendation has no action to consider~~Pending on the outcome of Japan/SAE discussion.

5.1.2.2.1.5 Hydraulic Residual Pressure Test. The storage container will be pressurized to 180%NWP and held 30 seconds without burst. [Equivalent to 5.1.2.2.1.5]

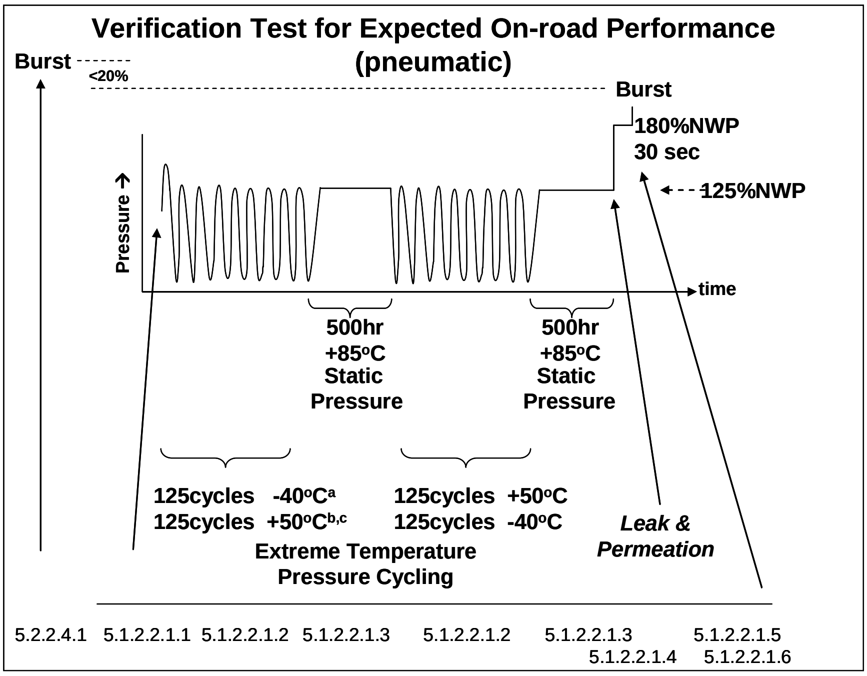
5.1.2.2.1.6 Residual Burst Strength Test . The storage container will undergo a hydraulic burst test to verify that the burst pressure is within 20% of the baseline burst pressure determined in 5.1.2.2.4.1. [Equivalent to 5.1.2.2.1.6]

5.1.2.2.2 **Verification Test for Expected On-road Performance (Pneumatic sequential tests)**

A hydrogen storage system must not leak during the following sequence of tests, which are illustrated in Figure 5.1.2.2.2. Specifics of applicable test procedures for the hydrogen storage system are provided in Section 6.

- ~~Comment by TUV: Is one sample sufficient to provide reliable results on the system performance?~~
- Germany will submit a proposal to address the sample size issue.

<u>SGS-6 Discussion</u>: Conformity of production is ensured by the batch and routine test to ensure that the design qualification test is representative. Batch and routine tests will be added according to SAE J2579.



a 5 cycles after equilibration @ -40ºC, <-35ºC fuel; 5 equilibrated cycles with +20ºC fuel
b 5 cycles after equilibration @+50ºC, <-35ºC fuel
c Maintenance defuel rate ≥50cy

Figure 5.1.2.2.2 Verification Test for Expected On-Road Performance (pneumatic)

5.1.2.2.2.1 Proof Pressure Test: A system will be pressurized to 150%NWP.

5.1.2.2.2.2 Fueling Performance: Extreme Temperature Pressure Cycling Test (pneumatic). The system will be pressure cycled (repeatedly filled to 125% NWP and defueled to <2MPa) using hydrogen gas for 500 cycles. Half of the cycles will be performed at extreme ambient temperatures of 50C, and half at -40C. The hydrogen gas fuel temperature will be <-35C. Five of the cycles will be performed after temperature equilibration at 50C, and five cycles after equilibration at -40C; an additional five cycles will be performed with >20C fuel after ambient-temperature equilibration at -40C. Fifty of the cycles will be performed using the maintenance defueling rate.

~~9.~~● ISO-member recommendation (slide 15): tests should be hydraulic tests done in parallel and supplemented by material tests to reduce testing time.

● ISO will provide a detailed proposal outlines the specific tests that should be done hydraulically. **Provide the powertech report.**

SGS-6 Discussion:
1) The systems will be used with high pressure hydrogen, not hydraulic fluids; many failure modes occurring with high pressure hydrogen do not occur with hydraulic testing – systems that have passed the historical CNG tests (equivalent to ISO TS) have failed the tests proposed by OICA under conditions that would have occurred in on-road driving.

Test convenience (less time and facility requirements) is not a substitute for safety assurance. ***To be verified by the powertech report.***
2) real-world stresses occur in sequence, not in parallel – it is not sufficient for a container to be able to handle one type of stress (parking or fueling) but not both. Static exposure to high pressure hydrogen caused infusion of hydrogen into materials and interfaces – potential causes of failure not replicated by hydraulic testing or testing with another gas. Given the lack of experience with 70MPa and hydrogen in vehicle applications, it is necessary to demonstrate capability to handle on-road conditions – the inconvenience of test time is manageable -- only a few more weeks than currently required for CNG testing.

5.1.2.2.2.3 Parking Performance Verification Test: Extreme Temperature Static Pressure Test (pneumatic). The system will be held at 125%NWP with hydrogen gas for 1000 hours at 85C. The parking performance test will be performed with 500 hours conducted after the first half of pressure cycles in 5.1.2.2.1.1 at each temperature, and the remaining 500 hours after the remaining pressure cycles in 5.1.2.2.1.1.

5.1.2.2.2.4 Leak/Permeation Test. The system will be fully filled with hydrogen gas and held at a temperature of at least 55 °C to stabilize and measure the total discharge rate due to leakage and permeation. The maximum allowable discharge from the compressed hydrogen storage system is 150 ml/min for standard passenger vehicles. [The maximum allowable discharge for systems in larger vehicles is R*150 Ncc/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.]

If the measured permeation rate is greater than 0.005 mg/sec (3.6 cc/min), then a localized leak test shall be performed to ensure no point of localized external leakage is greater than 0.005 mg/sec (3.6 cc/min).

- ~~10.~~ HySafe alternative (revised since China meeting) is 6 Nml/hr/L at 15C, 8 ml/hr/L at 20C and 90 ml/hr/L at 55C.
- OICA/SAE/HySafe will submit a proposal for new requirement for leak/permeation requirement.

- ~~11.~~ ISO-member recommendation (slide 15): reconsider the permeation rate.
  SGS-6 Discussion: The HySafe approach and the OICA approach are nearly identical in terms of first identifying the permeation limit for minimal garage size at 55C at end-of-life. In the OICA proposal, the permeation test replicates these conditions for a direct assessment of permeation suitability. HySafe uses a very rough estimate of change in permeation during service life and limited data on changes in permeation with temperature to estimate a corresponding permeation limit at beginning-of-life and lower temperatures (15 and 20C) -- according to the HySafe leader for permeation, this was done to avoid too much change from the CNG approach for more ready familiarity, and a HySafe statement of permeation limit at 55C would be appropriate as an option that would avoid the imprecision that results from the HySafe estimates of temperature and lifetime-wear factors. HySafe converts the

system values into worst-case limits per individual container; SAE is likewise considering a value for individual containers

~~□OICA will give an updated summary of HySafe and SAE permeation limits at the next session.~~
~~□*US comments: Remove localized leak test. This is appropriate for production quality check but not for regulation.*~~

5.1.2.2.2.5 Residual Proof Pressure Test . The storage container will be pressurized to 180%NWP and held 30 seconds without burst.

5.1.2.2.2.6 Residual Strength Burst Test (hydraulic): The storage container will undergo a hydraulic burst test to verify that the burst pressure is $\geq$ 80% BP_0, the baseline initial burst pressure determined in 5.1.2.2.4.1.

5.1.2.3 Performance Test Requirements for Criteria-Qualified Systems

5.1.2.3.1 Expected Service and Durability Performance Test *(Comment: This § is still under investigation)*

This § is still under investigation within Japan, OICA and SAE. Detailed information will be provided for the next SGS meeting.

The container manufacturer shall evaluate hydrogen effect on liner material by material test. Applicable test procedures for the liner material are provided in Annex **TBD**.

5.1.2.3.2 Expected Service and Durability Performance Test(hydraulic)

The hydrogen storage vessel shall not burst or exhibit unacceptable leak when subjected to the following sequence of exposures, as illustrated in Figure 3:

→ Routine Production Quality Tests (5.2.3.1)
  → Drop Test (5.2.2.2.1)
    → Surface Damage and Chemical Exposure (5.2.2.2.2)
      → Parking Performance Verification Test (5.2.2.4.1.1)
        → Fueling Performance Verification Test (5.2.2.4.1.2)
          → Proof Pressure Test at 180% NWP (5.2.2.1.4)
            → Residual Strength Burst Test (5.2.2.1.5)

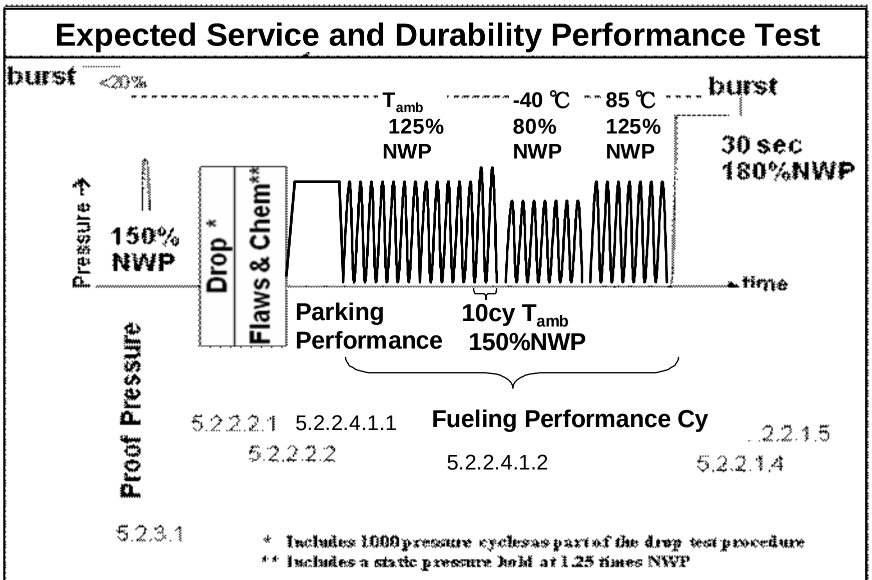


Figure 3 – Compressed Hydrogen Storage Expected Service and Durability Test

5.1.2.3.2.1 Parking performance verification test: static pressure exposure at extreme temperature

The hydrogen containers are pressurized hydraulically to 125% NWP and held for 1000 hrs at +85 °C.

5.1.2.3.2.2 Fueling Performance Verification Test: Extreme temperature and Extended Usage

The container shall not leak or burst after exposure to pressure cycles. The required number of test cycles is defined in 5.2.2.

a. Half (50%) of the Fueling Performance Test Cycles shall be conducted after Parking Performance Verification Test as illustrated in Figure 3.

Pressure cycling tests of < 2 MPa to 125% NWP are conducted at 15 – 25 °C ambient temperature. The tests are performed on the container using a non-corrosive fluid at 15 – 25 °C.

- The first 1000 cycles are conducted on vessels as part of drop tests in 5.2.2.2.1 per the test procedure defined in Annex **TBD**.
- The remaining 1750 cycles are conducted on one vessel that has been exposed to a shoulder drop impact (5.2.2.2.1) and to surface damage and chemicals (5.2.2.2.2). Chemical exposures are maintained throughout the pressure cycling. The last 10 cycles are performed at 150% NWP.

b. Half of the Fueling Performance Test Cycles shall be conducted after ambient temperature pressure cycles as illustrated in Figure 3.

- Half of these cycles (one-fourth of the total Fueling Performance Test Cycles) are conducted at < 2 MPa to 80% NWP with non-corrosive fluid at □–40 °C.
- Half of these cycles (one-fourth of the total Fueling Performance Test Cycles) are conducted at< 2 MPa to 125% NWP with non-corrosive fluid at ≥85 °C.

During pressure cycling, the containers shall show no evidence of rupture, unintended release or physical deterioration such as fiber unraveling.

The hydrogen container shall then be pressurized to 180% NWP and held for 30 seconds without rupture or evidence of leak.

5.1.2.3.3 Permeation Test

The container (limited to Type IV containers) shall be pressurized to more than nominal working pressure for 1,000 cycles at a rate of more than 1 time per hour.
The container shall be held at a temperature of not less than 15 deg-C to stabilize and measure the permeation rate. The permeation test requires the steady state permeation rate for hydrogen gas shall be less than 5,00 cm3 of hydrogen per hour per liter water capacity.(Annex TBD)

- This § is still under investigation within OICA and SAE. Japan will justify this permeation limit. Detailed information is expected for the next SGS meeting.

5.1.2.4 Verification Test for fail-safe Conditions

At least one system must be subjected to each of the following fail-safe conditions and demonstrate the absence of rupture. Specifics of test procedures are provided in Section 6.

5.1.2.4.1 Engulfing Fire (Bonfire) Test. A hydrogen storage system will be pressurized to NWP and exposed to an engulfing fire. If activated, temperature-activated pressure relief device will release the contained gases in a controlled manner.

- Canada and US Comment: Localized fire test is under consideration.
- ~~ISO member recommendation (slide 19): the bonfire test should be included.~~

SGS-6 Discussion: the bonfire test is in the draft GTR; however, ruptures of high pressure vessels continue to occur because localized fire is not accommodated by the bonfire test.

5.1.4 Markings

Tank label will contain the NWP, date of manufacture, and date of 15 year lifetime.

- No consensus on the OICA proposal
- ~~Comment by TUV: Lifetime has to be considered~~
- Members are requested to provide recommendations for markings/labels.

]

5.2 Vehicle fuel system: This section specifies requirements for the integrity of the hydrogen fuel system.

Re-number

Three open issues:

1. **Overpressure protection for the low pressure system.**
2. **Airtightness test.**
3. **Shut-off valve for storage system: one per container or one per system.**
- **Co-sponsors will discuss with project manager.**

5.2.1 Requirements – in use:

5.2.2 Gas fueling port: Gas fueling port shall prevent reverse flow.

5.2.1.1 Hydrogen discharge system:

5.2.1.1.1 The outlet of the vent line, if present, for hydrogen gas discharge from TPRD(s) of the storage system shall be ~~covered~~protected, e.g. by a cap. This~~ is~~ ~~will~~ will be ~~accomplished~~verified by visual inspection.

5.2.1.1.2 The hydrogen gas discharge from TPRD(s) of the storage system shall not be directed:

a) into or towards the vehicle passenger or luggage compartments
b) into or towards any vehicle wheel housing
c) towards hydrogen gas containers
d) forward from the vehicle, or horizontally from the back or sides of the vehicle

The hydrogen gas discharge from **other pressure relief systems** 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
d) towards hydrogen gas containers

5.2.1.2 Single failure of hydrogen fuel system:

[If a single failure of the hydrogen system results in a hydrogen concentration in air greater than 4% by volume within the passenger compartment, luggage compartment, and spaces within the vehicle that contain unprotected ignition sources, the main hydrogen shutoff valve(s) shall close and provide warning.

The enclosed spaces that contain the storage system shall not contain unprotected ignition sources. All spaces containing the hydrogen storage system shall vent to the outside of the vehicle]

[1. Hydrogen leakage and/or permeation from the hydrogen storage system shall not be allowed to directly vent to the passenger, luggage, or cargo compartments.

2. If a single failure downstream of the main hydrogen shutoff results in a hydrogen concentration greater than 4%, by volume in air in the enclosed or semi-enclosed spaces of the vehicle then the main shutoff shall be closed and a warning to the driver shall be provided per 5.2.1.2.3.

Need definitions for "unprotected ignition source"

5.2.1.2.1 Any single failure downstream of the main hydrogen shut off valve shall not result in a hydrogen concentration in air of 4% or more by volume within the passenger compartment.

5.2.1.2.2 If a single failure downstream of the main hydrogen shut off valve results in a hydrogen concentration of 4% by volume in air in the enclosed or semi-enclosed spaces within the vehicle that are not suitable for flammable gases then the main hydrogen shutoff valve shall be closed and a warning to the driver shall be provided per 5.2.1.2.3. The vehicle manufacturers shall provide a list of spaces that are suitable for flammable gases which are exempted from this requirement.

Test procedure stays in brackets; OICA will validate and revise the test procedure.

Add a requirement for failure in upstream (i.e. the storage system)

- OICA will provide new proposal to address hydrogen leakage.

5.2.1.2.3 Driver warning: The vehicle shall be equipped with a visual indicator (e.g. tell-tale) that provides a warning to the driver in the event of 5.2.1.2.2 or in the event of a malfunction of the hydrogen leakage detection system.

[The vehicle shall be equipped with a visual tell-tale(s) that provides a warning to the driver of (1) the hydrogen detection system malfunction or (2) in the event of unintended hydrogen leakage as described in section 5.2.1.2.2. The tell-tale(s) shall meet the following items:

(a) Shall be displayed in direct and clear view of the driver while in the driver's designated seating position with the driver's seat belt fastened;
(b) Shall appear perceptually upright to the driver while driving;
(c) Shall be yellow or amber in color if the detection system is malfunction and shall be red in the event of 5.2.1.2.2;
(e) When illuminated, shall be sufficiently bright to be visible to the driver under both daylight and night time driving conditions, when the driver has adapted to the ambient roadway light conditions;
(f) The detection malfunction tell-tale shall illuminate when a malfunction exists and shall remain continuously illuminated as long as the malfunction exists, whenever the ignition locking system is in the "On" ("Run") position;
(g) Shall extinguish at the next ignition cycle after the malfunction has been corrected;]

- Use UNECE- R121 for terminologies

5.2.2.3 Fuel cell / vehicle discharge system: At vehicle exhaust system's point of discharge, the hydrogen concentration level shall (1) not exceed 4% average by volume during any moving three-second time interval during normal operation including start-up and shutdown (2) and not exceed 8% at anytime.

OICA will provide justification for part A

5.2.2 Requirements - post crash

5.2.2.1 Fuel leakage limit: the rate of uncontrolled hydrogen gas leakage measured and calculated by 6.1 shall not exceed an average of ~~120~~ 118 NL per minute within 60 minutes after the crash.

Use J2578 calculation for 118 NL.
Use Japan's informal paper for justification in part A

5.3 Electric safety

5.3.1 Purpose: This section specifies the requirements for vehicle's high voltage system.

5.3.2 Requirements and test procedures - in-use

See OICA proposal

5.3.2.1 Performance requirements

5.3.3 Requirements and test procedures - post crash

See OICA proposal

5.3.3.1 Performance requirements

5.3.4 Markings (renumber)

[A label shall be provided close to the receptacle, for example, inside a refilling hatch, showing the following information: gas type (GH2 or LH2) "xx" MPa for GH2-storage systems where "xx" = nominal working pressure of the container(s).]

- Should we leave this for contracting party to decide?
- Members are requested to provide information for the marking.

6 Test conditions and procedures

Need test validation

6.1 [Demonstration of fuel system integrity crash test compliance

The crash tests used to evaluate post-crash hydrogen leakage are those already applied in the respective jurisdictions.

To evaluate possible hydrogen discharge following the vehicle crash tests, the following procedure should be used.

a) Compressed Gaseous Hydrogen Storage:

The gas container shall be filled with helium to minimum 90% of the nominal working pressure. The main stop valve and shut-off valves, etc. for hydrogen gas, located in the downstream hydrogen gas piping, shall be kept open immediately prior to the impact.

The pressure and temperature of the gas shall be measured immediately before the impact and 60 minutes after the impact either inside the gas container or upstream of the first pressure-reducing valve downstream of the gas container.

The rate of hydrogen gas leakage shall be measured by the following procedure.
The helium gas pressure immediately before the impact and 60 minutes after the impact, upstream of the first pressure-reducing valve either within the gas container or the one

located downstream of the gas container shall be converted to the pressure at 0°C using equation1.

Equation 1: $P_0' = P_0 \text{ x } \{273 / (273 + T_0)\}$
where:
P_0' : Helium gas pressure converted to pressure at 0 °C before impact (MPa abs)
P_0 : Measured helium gas pressure before impact (MPa abs)
T_0 : Measured helium gas temperature before impact (°C)

$P_{60}' = P_{60} \text{ x } \{273 / (273 + T_{60})\}$
where:
P_{60}' : Helium gas pressure converted to pressure at 0 °C 60 minutes after impact (MPa abs)
P_{60} : Measured helium gas pressure 60 minutes after impact (MPa abs)
T_{60} : Measured helium gas temperature 60 minutes after impact (°C)

The gas density calculated from equation 2 before the impact and 60 minutes after the impact shall be calculated using the pressure at 0°C converted from the helium gas pressure upstream of the first pressure-reducing valve within the gas container or the one located downstream of the gas container obtained from equation 1.

Equation 2: $\rho_0 = -0.0052 \text{ x } (P_0')^2 + 1.6613 \text{ x } P_0' + 0.5789$
where:
ρ_0 : Helium gas density before impact (kg/m^3)
$\rho_{60} = -0.0052 \text{ x } (P_{60}')^2 + 1.6613 \text{ x } P_{60}' + 0.5789$
where:
ρ_{60} : Helium gas density 60 minutes after impact (kg/m^3)

The helium gas volume before the impact and 60 minutes after impact shall be calculated from equation 3 using the gas density obtained from equation 2. However, the internal volume shall be the internal volume of the gas container in cases where the helium gas pressure has been measured inside the gas container; and the internal volume of the container down to the first pressure-reducing valve located downstream of the gas container in cases where the helium gas pressure has been measured upstream of the first pressure-reducing valve located downstream of the gas container.

Equation 3: $Q_0 = \rho_0 \text{ x } V \text{ x } (22.4 / 4.00) * 10^{-3}$
where:
Q_0 : Helium gas volume before impact (m^3)
V : Internal volume (L)

$Q_{60} = \rho_{60} \text{ x } V \text{ x } (22.4 / 4.00) * 10^{-3}$
where:
Q_{60} : Helium gas volume 60 minutes after impact (m^3)
V : Internal volume (L)

The rate of helium gas leakage shall be calculated.
$\Delta Q = (Q_0 - Q_{60}) \text{ x } 10^3$
$RHe = \Delta Q / 60$
where:

ΔQ : Volume of helium gas leakage 60 minutes after impact (NL)
RHe : Rate of helium gas leakage (NL/min)

The rate of helium gas leakage shall be converted to the rate of hydrogen gas leakage.
RH = 1.33 x RHe
where:
RH : Rate of hydrogen gas leakage (NL/min)

b) Liquid Hydrogen Storage:

The fuel storage container shall be filled with liquid nitrogen (LN2) to minimum the mass equivalent of the maximum quantity of LH2 that may be contained in the inner vessel and then the system shall be pressurized with a gaseous N2 up to typical operating pressure.

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

After the collision, the liquid hydrogen storage system must be tight, i.e. bubble free* if using detecting spray. No uncontrolled release of the test fluid is allowed.

** With bubble detection spray, any leakage in the range above 0,1Pa l/s can be detected. In case of N2 used as test fluid, the corresponding detectable hydrogen leakage would be about 0,5 Pa l/s (that is far below 1 NL per minute!).*]

[6.2 Demonstration of compliance for single failure condition

[Preparation:
The test shall be conducted without any influence of wind.
Special attention shall be paid to the test environment as during the test flammable mixtures of hydrogen and air may occur.
Prior to the test the vehicle has to be prepared to allow remotely controllable hydrogen releases from the hydrogen system. The number and location of the release points downstream of the main hydrogen shutoff valve shall be defined by the vehicle manufacturer taking worst case leakage scenarios into account.
Only for the purpose of the test hydrogen concentration detectors have to be installed in enclosed or semi enclosed volumes on the vehicle.
If there is structure taken to prevent hydrogen from intruding into passenger compartments, it is not necessary to have H2 concentration measurement points in the passenger compartments.

Example hydrogen concentration measurement locations can be found in the document “Examples of hydrogen concentration measurement points for testing”.

Procedure:
i) Vehicle doors, windows and other covers shall be closed.
ii) Start the propulsion system, allow it to warm up to its normal operating temperature and leave it operating at idle for the test duration.
iii) A leak shall be simulated using the remote controllable function.

iv) The hydrogen concentration shall be measured continuously until the concentration does not rise anymore for 3 minutes or until the main hydrogen shutoff valve is closed.
v) If during the test the hydrogen concentration at one of the measurement locations exceeds 4% significantly, the test shall be terminated.]*

[ ] this part of the proposal still needs to be confirmed]*

[6.3 Demonstration of compliance for fuel cell vehicle exhaust system

i) The fuel cell system of the test vehicle shall be warmed up. (is this the worst case scenario? Should this be removed to include all vehicle's stages)
ii) The measuring device shall be warmed up before use.
iii) Place the measuring section of the measuring device on the centre line of the exhaust gas flow within 100 mm from the exhaust gas outlet.
iv) Perform the test procedure below while continuously measuring the hydrogen concentration:
With the vehicle in a stationary state, start the fuel cell system. After a lapse of at least one minute turn off the system and continue the measurement until the fuel cell system shut down procedure is completed.]

OICA- provides the response time for the measuring device

Japan will submit its test procedure for consideration.

6.4 Test Procedures for Hydrogen Storage

6.4.1 Material Qualification

6.4.1.1 Plastic liner tensile test. For containers with plastic liners, two platic liners shall be tested at -40oC in accordance with ISO 527-2. The tensile yield strength and ultimate elongation shall be within the manufacturer's specifications.

6.4.1.2 Plastic liner softening temperature test. For containers with plastic liners, the softening temperature of polymeric materials from finished liners shall be determined based on the A50 method in ISO 306. The softening temperatue shall be $\geq$ 100^{o}C.

6.4.1.3 Glass transition temperature test. For containers with composite wraps, the glass transition temperature of resin materials shall be determined in accordance with ASTM D3418. Test results shall be within the manufacturer's specifications.

6.4.1.4 Resin shear strength test. For containers with composite wraps, resin materials shall be tested on a sample coupon respresentative of the over-wrap in accordance with ASTM D2344. After boiling in water for 24 hours the inimum shear strength of the composite shall be 13.8MPa.

6.4.1.5 Coating test. For containers with external environmental coatings, coatings shall be evaluated as follows:

a) adhesion strength based on ISO 4624; the coating shall exhibit an adhesion rating of 4.
b) flexibility based on ASTM D522 Method B with a 12.7 mm mandrel at the specified thickness at -20^{o}C; the coating shall exhibit no aparent cracks
c) impact resistance in accordance with ASTM D2792. The coating at room temperature shall pass a forward impact test of 18 J.
d) water exposure based on ASTM G154 using an exposure of 1000 hours. There shall be no evidence of blistering. The adhesion shall meet a ration of 3 when tested in accordance with ISO 4624.
e) salt spray exposure in accordance with ASTM B117 using an exposure of 500 hours. There shall be no evidence of blistering. The adhesion shall meet a rating of 3 when tested in accordance with ASTM D3359.

[6.4.1.6 Metal hydrogen compatibility. Metal container bodies or liners will be either stainless steel SUS316L or ~~s~~aluminum A6061.]

- Provide justification for limiting to these 2 metal.

6.4.2 Storage System Performance Test Requirements (5.1.2.)

6.4.2.1 Proof Pressure Test. The system should be pressurized smoothly and continually until the target test pressure level is reached and then held for at least 30 seconds. The component should not leak or suffer permanent deformation. All mechanical components should be functional after completion of the test.

6.4.2.2 Pressure Cycling Test (pneumatic). At the onset of testing, stabilize the storage system at the specified temperature and fuel level at least 24 hrs in a temperature-controlled chamber. Maintain the specified temperature within the test environment throughout the remainder of the test. (When required in the test specification, the system temperature should be stabilized at the external environmental temperature between pressure cycles.) Pressure cycle between <2 MPa and the specified maximum pressure. Control the fill rate to a constant-pressure 3-minute ramp rate; control the temperature of the dispensed hydrogen gas to <-35^{o}C (except where otherwise specified). Control the defueling rate to no less 2g/sec or the intended vehicle's maximum fuel-demand rate.
If devices and/or controls are used in the vehicle to prevent an extreme internal temperature, the test may be conducted with these devices and/or controls (or equivalent measures).

6.4.2.3 Extreme Temperature Static Pressure Test. Pressurize the storage system to 125% NWP in temperature-controlled chamber held at +85^{o}C.

6.4.2.4 Leak/Permeation Test.

A storage system shall be fully filled with hydrogen gas (full fill density equivalent to 100% NWP at 15 °C is 125% NWP at 85 °C) and held at 55^{o}C in a sealed container. The total steady-state discharge rate due to leakage and permeation from the storage system shall be measured. Alternatively, the leakage and permeation measurement may be performed at any temperature above 55 °C.

A bubble test (or alternative method with sufficient accuracy) to verify local leakage should be conducted as follows: a) The exhaust of the shutoff valve (and other internal connections to hydrogen systems) may be capped for this test (as the test is focused at external leakage). At the discretion of the tester, the test article may be immersed in the leak-test fluid or leak-test fluid applied to the test article when resting in open air. Bubbles can vary greatly in size, depending on conditions. In general, the tester should estimate the gas leakage based on the size and rate of bubble formation. b) When using standard leak-test fluid, the bubble size is expected to be approximately 1.5 mm in diameter and the resultant allowable rate of bubble generation is about 2030 bubbles per minute. Even if much larger bubbles are formed, the leak should be readily detectable. For example, the allowable bubble rate for 6 mm bubbles is still approximately 32 bubbles per minute.

6.4.2.5 Burst Test. The burst test shall be conducted at ambient temperature using a non-corrosive fluid. The rate of pressurization shall be □1.4 MPa/s for pressures higher than 150% of the nominal working pressure. If the rate exceeds 0.35 MPa/s at pressures higher than 150% NWP, then either the container shall be placed in series between the pressure source and the pressure measurement device, or the time at the pressure above a target burst pressure shall exceed 5 seconds. The burst pressure of the container shall be recorded.

6.4.2.6 Drop (Impact) Test.

One or more storage containers will be drop tested at ambient temperature without internal pressurization or attached valves. All drop tests may be performed on one tank, or individual impacts on a maximum of 3 tanks. The surface onto which the tanks are dropped should be a smooth, horizontal concrete pad or similar flooring. The tank(s) should be tested in the following sequence:

a) Drop once from a horizontal position with the bottom 1.8 m above the surface onto which it is dropped.
b) Drop once onto each end of the tank from a vertical position with a potential energy of not less than 488J, but in no case should the height of the lower end be greater than 1.8 m.
c) Drop once at a 45 ° angle, and then for non-symmetrical and non-cylindrical tanks rotate the tank through 90 ° along its longitudinal axis and drop again at 45 °C with its center of gravity 1.8 m above the ground. However, if the bottom is closer to the ground than 0.6 m, the drop angle should be changed to maintain a minimum height of 0.6 m and a center of gravity of 1.8 m above the ground.

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

~~1.~~6.4.2.7 Surface damage and Chemical Exposure Test. The test should proceed in the following sequence:

a) Surface Flaw Generation: Two longitudinal saw cuts are made on the bottom outer surface of the horizontal storage container along the cylindrical zone close to but not in the shoulder area. The first cut will be at least 1.25 mm deep and 25 mm long toward the valve end of the vessel. The second cut will be at least 0.75 mm deep and 200 mm long toward the end of the tank opposite the valve.
b) Pendulum Impacts: The upper section of the horizontal storage container should be divided into five distinct (not overlapping) areas 100 mm in diameter each (see Figure C1). After 12 hrs preconditioning at –40 °C in an environmental chamber, the center of each of the five areas should sustain impact of a pendulum having a pyramid with equilateral faces and square base, the summit and edges being rounded to a radius of

3 mm. The center of impact of the pendulum should coincide with the center of gravity of the pyramid. The energy of the pendulum at the moment of impact with each of the five marked areas on the containment vessel should be 30J. The tank should be secured in place during pendulum impacts and not under pressure.

c) Chemical Exposure: Each of the 5 areas preconditioned by pendulum impact should be exposed to one of five solutions: 1) 19% (by volume) sulfuric acid in water (battery acid), 2) 25% (by volume) sodium hydroxide in water, 3) 5% (by volume) methanol in gasoline (fluids in fueling stations), 4) 28% (by volume) ammonium nitrate in water (urea solution), and 5) 50% (by volume) methyl alcohol in water (windshield washer fluid).

d) Orient the test vessel with the fluid exposure areas on top. Place a pad of glass wool approximately 0.5 mm thick and 100 mm in diameter on each of the five preconditioned areas. Apply an amount of the test fluid to the glass wool sufficient to ensure that the pad is wetted across its surface and through its thickness for the duration of the test.

e) The exposure of the vessel with the glass wool should be maintained for 48 hrs at 1.25 times NWP before the vessel is subjected to further testing.

6.4.2.8 Pressure Cycling Test (Hydraulic). The test shall be performed in accordance with the following procedure:

a) Fill the container with a non-corrosive fluid.
b) Stabilize the temperature of the container at the specified temperature at the start of testing; maintain the environment in the specified temperature range for the duration of the testing; the container temperature may vary.
c) Pressure cycle between <2 MPa and the target pressure at a rate not exceeding 10 cycles per minute for the specified number of cycles.

6.4.2.9 Engulfing Fire (Bonfire) Test.

The storage system should be placed horizontally with the container bottom approximately 100 mm above the fire source. A uniform fire source of 1.65 m in length should provide direct flame impingement on the storage system across its entire diameter (width). Metallic shielding should be used to prevent direct flame impingement on tank valves, fittings, and/or pressure relief devices. The metallic shielding should not be in direct contact with the pressure relief devices or tank valve. Any fuel may be used for the fire source provided it supplies uniform heat sufficient to maintain the specified test temperatures until the system is vented. The arrangement of the fire should be recorded in sufficient detail to ensure the rate of heat input to the storage system is reproducible. Any failure or inconsistency of the fire source during a test would invalidate the result.

Surface temperatures on the containment vessel should be monitored by at least three thermocouples located within 25 mm of the bottom of the vessel and spaced not more than 0.75 m apart. Metallic shielding should be used to prevent direct flame impingement on the thermocouples. Alternatively thermocouples may be inserted into blocks of metal measuring less than 25 mm on a side. Thermocouple temperatures and vessel pressure should be recorded at intervals of every 10 sec or less during the test.

The system should be pressurized with hydrogen gas to NWP and tested in the orientation used in the vehicle. For tanks of length 1.65 m or less, the center of the tank should be positioned over the center of the fire source. For tanks of length greater than 1.65 m, the tank should be positioned so that if the tank is fitted with a pressure relief device at one end, the fire source should commence at the other end of the tank; if the tank if fitted with pressure relief devices at more than one location along the length of the tank, the center of the fire source should be centered midway between the pressure relief devices that are separated by the greatest horizontal distance.

Within 5 min of ignition, the temperature of at least one thermocouple should indicate at a minimum temperature of 590 °C. This minimum temperature should be maintained for the remainder of the test.

The tank should vent through the thermally activated pressure relief device. If the tank vents through a fitting or valve other than this pressure relief device then the test should be repeated.

The results should summarize the elapsed time from ignition of the fire to the start of venting through the pressure relief device(s), and the maximum pressure and time of evacuation until a pressure of less than 10 bar is reached.

6.4.2.10 Penetration Test. A storage container pressurized to NWP with air or nitrogen shall be penetrated by an armor piercing bullet with a diameter of 7.62 mm (0.3 in) or greater. The bullet shall completely pass through at least one side wall of the container.

7. Annexes