DRAFT

8 February 2011 SGS-12

⇒⇒ SGS-9 & 10 Decisions & Directions

⏩⏩ Contracting Party Proposals & Comments

Draft text resulting from SGS Discussion

LH2 text from BMW

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 FUELED 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 .....

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UNITED NATIONS

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A. STATEMENT OF TECHNICAL RATIONALE AND JUSTIFICATION

A.1 INTRODUCTION

A 1.1 In the ongoing debates over the need to identify new sources of energy and to reduce the emissions of green house gases, companies 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 emissions from the vehicle being virtually zero emission. In the late 1990's, the European Community allocated resources to study the issue under its European Integrated Hydrogen Project (EIHP) and forwarded the results, two ECE-drafts for compressed gaseous and liquefied Hydrogen, to UN-ECE. The follow-on project, EIHP2, initiated discussions on the possibility of a Global Technical Regulation for hydrogen fueled vehicles. 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.

A.1.2 For decades scientists, researchers and economists have pointed to hydrogen, in both compressed gaseous and liquid forms, as a possible alternative to gasoline and diesel as vehicle fuel. Ensuring the safe use of hydrogen as a fuel is a critical element in successful transitioning to a global 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 compressed gaseous form, lies in preventing catastrophic failures involving a combination of fuel, air and ignition sources as well as pressure and electrical hazards.

A.1.3 The governments have identified the development of regulations and standards as one of the key requirements for commercialization of hydrogen-fueled vehicles. Regulations and standards will help overcome technological barriers to commercialization, facilitate manufacturers' investment in building hydrogen-fueled vehicles and facilitate public acceptance by providing a systematic and accurate means of assessing and communicating the risk associated with the use of hydrogen vehicles, be it to the general public, consumer, emergency response personnel or the insurance industry.

A.1.4 The goals of this global technical regulation (GTR) are to develop and establish a GTR for Hydrogen Fuel Cell Vehicles (HFCV) that: (1) attains or exceeds the equivalent levels of safety as those for conventional gasoline fueled vehicles; and, (2) is performance-based and does not restrict future technologies.

A.2 GTR ACTION PLAN

A.2.1 Given that hydrogen-fueled 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.

A.2.2 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-fueled vehicles (ECE/TRANS/WP.29/AC.3/17). Under the agreed process, once AC.3 approved an action plan for the development of a GTR submitted by the co-sponsors, two subgroups were formed to address the safety and the environment aspects of the GTR. The subgroup safety (HFCV-SGS) reported to GRSP. HFCV-SGS was chaired by Japan. The chair for the group would be discussed and designated by summer of 2007. The environmental subgroup (HFCV-SGE) was chaired by the European Commission and reported to GRPE. In order to ensure communication between the subgroups and continuous engagement with WP.29 and AC.3, the project manager (Germany) coordinated and managed the various aspects of the work ensuring that the agreed action plan was implemented properly and that milestones and timelines were set and met throughout the development of the GTR. The initial stage of the GTR covers fuel cell (FC) and internal combustion engine (ICE), compressed gaseous hydrogen (CGH2) and liquid hydrogen (LH2) GTR. At a subsequent session of WP.29, the GTR action plan was submitted and approved by AC.3 (ECE/TRANS/WP.29/2007/41).

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A.2.3 In order to develop the GTR in the context of evolving hydrogen technologies, the trilateral group of co-sponsors proposes to develop the GTR in two phases:

a. Phase 1 (GTR for hydrogen-fueled vehicles):
Establish a GTR by 2010 for hydrogen-fueled vehicles based on a combined component level, subsystems, and whole vehicle approach. For the related crash testing, the GTR specifies that each contracting party will use its existing national crash tests but develop and agree upon a maximum allowable level of hydrogen leakage. The new Japanese national 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.

A.2.4 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 relief devices, and fuel lines.
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:
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 appropriate mitigating measures for hydrogen-fueled 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 in both pre- and post-crash situations.

A.3 DESCRIPTION OF TYPICAL HYDROGEN-FUELED FUEL CELL VEHICLES

A.3.1 VEHICLE DESCRIPTION

A.3.1.1 Hydrogen fueled vehicles can use either internal combustion engine (ICEs) or fuel cells to provide power; however, typically hydrogen-fueled vehicles are powered by fuel cell power systems. Fuel cell vehicles (HFCVs) have an electric drive-train powered by a fuel cell that generates electric power electrochemically from hydrogen. In general, HFCVs 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 HFCVs are likely to differ with regard to details of the systems and hardware/software implementations, the following major systems are common to most HFCVs:

- Hydrogen fueling system
- Hydrogen storage system
- Hydrogen fuel delivery system
- Fuel cell system
- Electric propulsion and power management system

A.3.1.2 A high-level schematic depicting the functional interactions of the major systems is shown in Figure A.1. Hydrogen is supplied to the fueling receptacle 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.

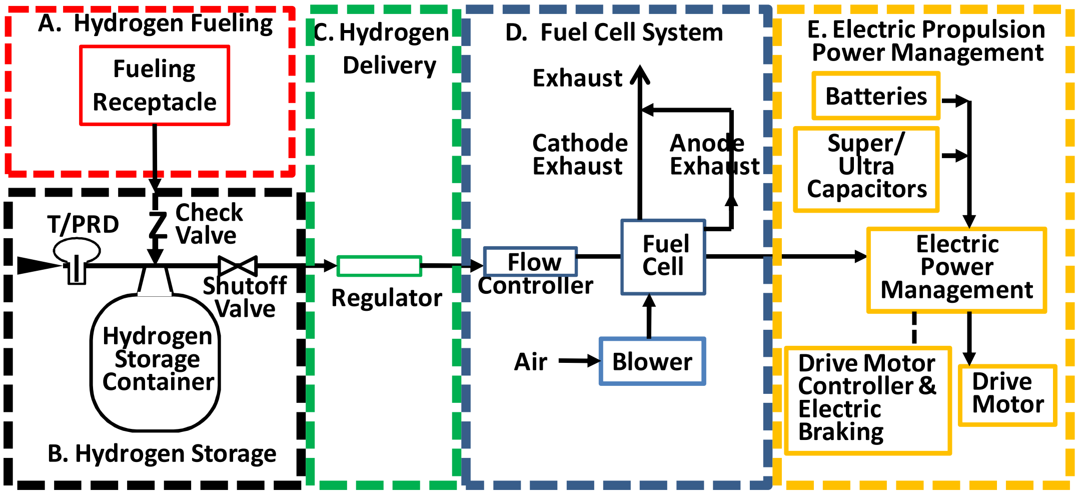


Figure A.1. Example of High-level Schematic of Key Systems in FCVs

A.3.1.3 Figure A.2 illustrates a typical layout of key components in the major systems of a typical fuel cell vehicle (HFCV). The fueling receptacle is shown in a typical position on the rear quarter panel of the vehicle. As with gasoline containers, hydrogen storage containers, whether compressed gas or liquefied hydrogen, are usually mounted transversely in the rear of the vehicle, but could also be mounted differently, such as lengthwise in the middle tunnel 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 within the vehicle to retain proper desired weight balance for proper handling of the vehicle.

A.3.1.4 A typical arrangement of componentry in a hydrogen fueled vehicle powered by a fuel cell is shown in Figure A.2.

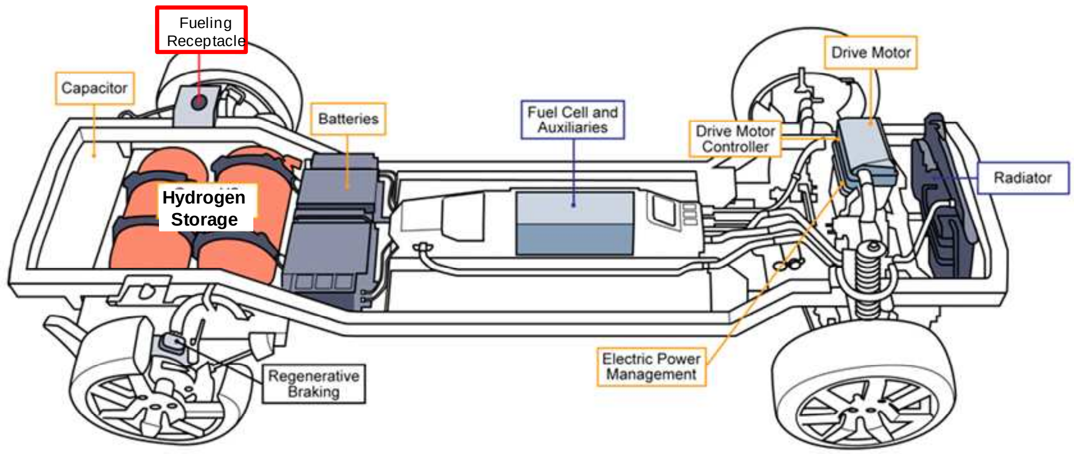


Figure A.2. Example of a Fuel Cell Vehicle

A.3.2 HYDROGEN FUELING SYSTEM

A.3.2.1 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 125% of nominal working pressure (NWP) to compensate for the effects of compression adiabatic heating during “fast fill”.

A.3.2.2 Regardless of state of the hydrogen, the vehicles are fuelled through a special nozzle on the filling stations to the fueling receptacle 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 fueling receptacle on the vehicle also contains a check valve (or other device) that prevents leakage of hydrogen out of the fueling receptacle in the event of a fault of the back-flow prevention in the hydrogen storage system.

A.3.2.3 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.

A.3.3 HYDROGEN STORAGE SYSTEM

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

A.3.3.1 COMPRESSED HYDROGEN STORAGE SYSTEM

A.3.3.1.1 Components of a typical compressed hydrogen storage system are shown in Figure A.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:

- the container,
- the check valve,
- the shut-off valve,
- the thermally-activated pressure relief device (TPRD)

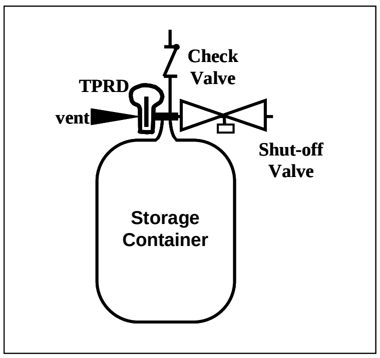


Figure A.3. Typical Compressed Hydrogen Storage System

A.3.3.1.2 The hydrogen storage containers store the compressed hydrogen gas. A hydrogen storage system may contain more than one container depending 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 (prior to 2010), hydrogen has typically been stored at a nominal working pressure of 35 MPa or at 70 MPa , with maximum fueling pressures of 125% of nominal working pressure (43.8 MPa and 87.5 MPs respectively). 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 pressure rise in the containers. As the temperature in the container cools after fueling, the pressure will reduce. By definition, the settled pressure of the system will be equal to the nominal working pressure when the container is at 15C. Different pressures (that are higher or lower or in between current selections) are possible in the future as commercialization proceeds.

A.3.3.1.3 Containers are currently constructed from composite materials in order to meet the challenge of high pressure containment of hydrogen at a weight 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 the gas sealing inner liner for structural integrity.

A.3.3.1.4 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).

A.3.3.1.5 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 storage system from down-stream systems or the environment.

A.3.3.1.6 In the event of a fire, thermally-activated pressure relief devices (TPRDs) vent, i.e., provide a controlled release of, the gas contained in the compressed hydrogen storage containers before the high temperatures in a fire degrade composite and metallic container materials, which could 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.

A.3.3.2 LIQUEFIED HYDROGEN STORAGE SYSTEM

A.3.3.2.1 Hydrogen gas has a low energy density per unit volume. To overcome this disadvantage, the liquefied hydrogen storage system (LHSS) maintains the hydrogen at cryogenic temperatures in a liquefied state.

A.3.3.2.2 A typical liquefied hydrogen storage system (LHSS) is shown Figure 4. Actual systems will differ in the type, number, configuration, and arrangement of the functional constituents. Ultimately, the boundaries of the LHSS are defined by the interfaces which can isolate the stored liquefied (and/or gaseous) hydrogen from the remainder of the fuel system and the environment. All components located within this boundary are subject to the requirements defined in this Section while components outside the boundary are subject to general requirements in Section 4. For example, the typical LHSS shown in Figure 4 consists of the following regulatory elements:

- liquefied hydrogen storage container(s),
- shut off devices(s),
- a boil-off system,
- Pressure Relief Devices (PRDs),
- the interconnecting piping (if any) and fittings between the above components.

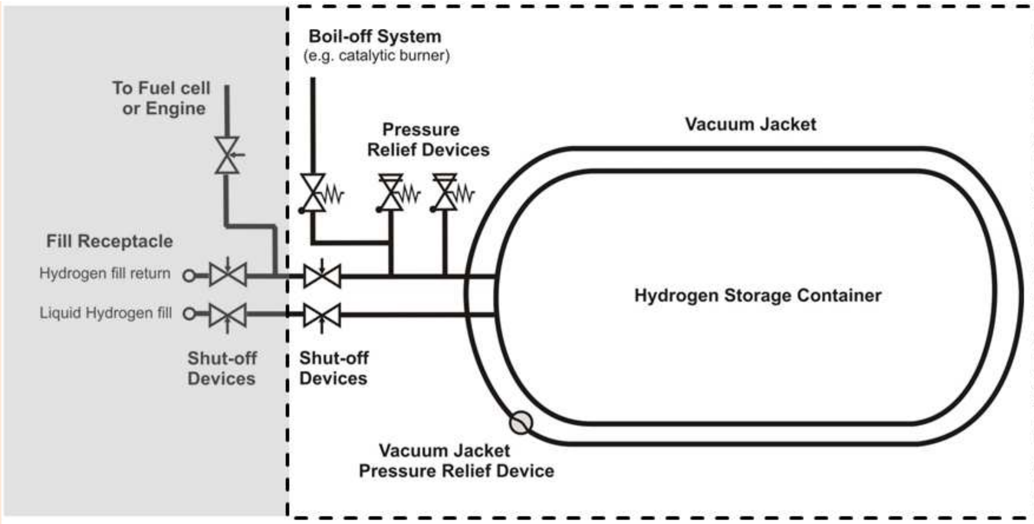


Figure 4. Typical Liquefied Hydrogen Storage System

A.3.3.2.3 During fueling, liquefied hydrogen flows from the fuelling system to the storage container(s). Hydrogen gas from the LHSS returns to the filling station during the fill process so that the liquefied hydrogen can flow into liquefied hydrogen storage container(s) without over pressurizing the system. Two shut-offs are provided on both the liquefied hydrogen fill and hydrogen fill return line to prevent leakage in the event of single failures.

A.3.3.2.4 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. Generally accepted rules or standards (such as those listed in the B7.2 annex) are advised to use for proper design of the storage container and the vacuum jacket.

A.3.3.2.5 During longer parking times of the vehicle, heat transfer will induce a pressure rise within the hydrogen storage container(s). A boil-off system limits heat leakage induced pressure rise in the hydrogen storage container(s) to a pressure specified by the manufacturer. Hydrogen that is vented from the LHSS may be processed or consumed in down-stream systems. Discharges from the vehicle resulting from over-pressure venting should be addressed as part of allowable leak/permeation from the overall vehicle.

A.3.3.2.6 In case malfunction of the boil-off system, vacuum failure, or external fire, the hydrogen storage container(s) are protected against overpressure by two independent Pressure Relief Devices (PRDs) and the vacuum jacket(s)is protected by a vacuum jacket pressure relief device.

A.3.3.2.7 When hydrogen is released to the propulsion system, it flows from the LHSS through the shut-off valve that is connected to the hydrogen fuel delivery system. In the event that a fault is detected in the propulsion system or fill receptacle, vehicle safety systems usually require the container shut-off valve to isolate the hydrogen from the down-stream systems and the environment.

A.3.4 HYDROGEN FUEL DELIVERY SYSTEM

A.3.4.1 The fundamental purpose of a hydrogen fuel delivery system is to reliably deliver hydrogen fuel to either an ICE or fuel cell stack at a specified pressure and temperature for proper engine or fuel cell operation over the full range of vehicle operating conditions. Hydrogen is delivered from the storage container(s) to the fuel cell stack or to the ICE via a series of valves, control valves, pressure regulators, filters, piping, and (a) possible (coolant) heat exchanger(s) or heaters. In the case of a liquefied hydrogen storage system, both liquid and gaseous hydrogen could be extracted from the storage so typically a coolant heat exchanger downstream the container shut-off device heats-up the hydrogen to the temperature range specified by the manufacturer. Similarly, in the case of compressed hydrogen storage, some thermal conditioning of the gaseous hydrogen may also be required, particularly in extremely cold, sub-freezing weather.

A.3.4.2 The fuel delivery system must reduce the pressure from levels in the hydrogen storage system to values required by the fuel cell or ICE system. In the case of 70 MPa compressed hydrogen storage system, for example, the pressure may have to be reduced from as high as 87.5 MPa to levels typically under 1MPa at the inlet of the fuel cell system and, respectively, typically under 1.5 MPA at the inlet of an ICE system. This may require 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, if necessary, 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.

A.3.5 FUEL CELL SYSTEM

A.3.5.1 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-fueled internal combustion engines (ICE).

A.3.5.2 As shown in Figure A.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.

A.3.5.3 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 glycol-water. Coolant pumps circulate the water through the fuel cells and then to the radiator.

A.3.5.4 The individual fuel cells are usually "stacked" or electrically connected in series such that the voltage is between 300 and 600 Vdc. Since fuel cells operate at 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.

A.3.6 ELECTRIC PROPULSION AND POWER MANAGEMENT SYSTEM

A.3.6.1 The electric power generated by the fuel cell is ultimately used to drive electric motors that ultimately propel the vehicle. As illustrated in Figure A.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; however, other configurations and rear-wheel drive are also viable options. 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.

A.3.6.2 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.

A.3.6.3 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.

A.4 RATIONALE FOR SCOPE, DEFINITIONS AND APPLICABILITY

A.4.1 Rationale for B. 2 Scope This GTR applies to hydrogen storage systems having nominal working pressures (NWP) of 70 MPa or less, with an associated maximum fueling pressure of 125% of the nominal working pressure. Systems with NWP up to 70 MPa include storage systems currently expected to be of commercial interest for vehicle applications. In the future, if there is interest in qualifying systems to higher nominal working pressures, the test procedures for qualification will be re-examined.

This GTR applies to fuel storage systems securely attached within a vehicle for usage throughout the service life of the vehicle. It does not apply to storage systems intended to be exchanged in vehicle refueling. This GTR applies does not apply to vehicles with storage systems using chemical bonding of hydrogen; it applies to vehicles with storage by containment of gaseous or liquid hydrogen.

The fueling infrastructure established prior to 2010 applies to fueling of vehicles up to 70 MPa NWP. This GTR does not address the requirements for the fueling station or the fueling station/vehicle interface.

This GTR provides requirements for fuel system integrity in vehicle crash conditions, but does not specify vehicle crash conditions. Contracting Parties under the 1998 Agreement are expected to execute crash conditions as specified in their national regulations.

A.4.2 Rationale for B.3.18 and B.3.19 Definitions of Service Life and Date of Removal from Service. These definitions pertain to qualification of the compressed hydrogen storage system for on-road service. The service life is the maximum time period for which service (usage) is qualified and/or authorized. This document provides qualification criteria for liquid and compressed hydrogen storage systems having a service life of 15 years or less (B.5.1). The service life is specified by the manufacturer.

The date of removal from service is the calendar date (month and year) specified for removal from service. The date of removal from service may be set by a regulatory authority. It would likely be no earlier that the date of manufacture plus the service life; it might be later; for example, to accommodate the period of time between manufacture and installation in a vehicle.

A.4.3 Rationale for B.4 Applicability of Requirements. The performance requirements in B.5 address the design qualification for on-road service. Additional requirements in Annex B.7 are applicable for Contracting Parties with Type Approval systems that address the conformity of mass production to units qualified to the requirements of B.5. The goal of harmonization of requirements as embodied in the United Nations Global Technical Regulations provides the opportunity to develop vehicles that can be deployed throughout Contracting Parties to achieve uniformity of compliance and resulting economies of scale; therefore, Type Approval requirements beyond those specified in Annex B.7 are not expected.

⇒⇒ Contracting Parties: review text above and below

It is expected that all Contracting Parties will recognize vehicles that meet the full requirements of this GTR as suitable for on-road service within their jurisdictions. In addition, any individual Contracting Party may also elect to develop different requirements for additional vehicles to qualify for on-road service within that the jurisdiction of that individual Contracting Party. For example:

(1) This GTR requires the use of hydrogen gas in fire testing of compressed gas storage (B.6.2.5), but an individual Contracting Party might elect to qualify vehicles for on-road service using either hydrogen or air as the test gas in fire testing. In that case, those vehicles qualified using air could be qualified for on-road service within the jurisdiction

of that individual Contracting Party but would not necessarily be recognized by other Contracting Parties as qualified for on-road service.

(2) Contracting Party A might elect to qualify vehicles using 5500 pressure cycles for compressed hydrogen storage (B.5.1. 2) and Contracting Party B might require 7500 cycles. In that case, vehicles qualified for on-road service by Contracting Party B would be recognized as suitable for on-road service in Contracting Party A, but vehicles meeting only the 5500 cycle requirement of Contracting Party A would not be recognized as suitable for on-road service in Contracting Party B. However, vehicles qualified for on-road service in Contracting Party A using 7500 cycles in testing would be recognized as suitable for on-road service in Contracting Party B.

(3) Contracting Parties with Type Approval systems would not necessarily recognize vehicles qualified for on-road service without compliance with requirements of Annex B.7.

A.5. RATIONALE FOR PERFORMANCE REQUIREMENTS, SCOPE & DEFINITIONS

A.5.1 COMPRESSED HYDROGEN STORAGE SYSTEM TEST REQUIREMENTS & SAFETY CONCERNS

The containment of the hydrogen within the compressed hydrogen storage system is essential to successfully isolating the hydrogen from the surroundings and down-stream systems. The system-level performance tests in Part B were developed to demonstrate capability to perform critical functions throughout service including fueling/de-fueling and parking under extreme conditions, and performance in fires.

Performance test requirements for all compressed hydrogen storage systems in on-road vehicle service are specified in PART B 5.1. These criteria apply to qualification of storage systems for use in new vehicle production.

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. Performance-based requirements address documented on-road stress factors and usages to assure robust qualification for suitability for vehicle service.

Qualification requirements for on-road service include:

B.5.1.1 Verification Tests for Baseline Metrics
B.5.1.2 Verification Test (Hydraulic) for Performance Durability
B.5.1.3 Verification Test (Hydrogen Gas) for Expected On-Road Performance
B.5.1.4 Verification Test for Service Terminating Performance

B.5.1.1 establishes metrics used in the remainder of the performance verification tests and in production quality control. B.5.1.2 and B.5.1.3 are the qualification tests that verify that the system can perform basic functions of fueling, defueling and parking under extreme on-road conditions without leak or rupture through-out the specified service life. B.5.1.4 provides confirmation that the system performs safely under the service terminating condition of fire.

The remainder of this section (A.5.1) specifies the rationale for the performance requirements established in Part B.5.1 for the integrity of the compressed hydrogen storage system.

Manufacturers are expected to ensure that all production units meet the requirements of performance verification testing in Part B.5.1.2. In addition, manufacturers are expected to monitor the reliability, durability and residual strength of representative production units throughout service life.

A.5.1.1. Rationale for B.5.1.1 The Design Qualification Tests for Baseline Metrics.

The Design Qualification Tests for Baseline Metrics have several uses: 1) verify that systems presented for design qualification (the qualification batch) are consistent in their properties (B.7.1.1.3), and are consistent with manufacturer's records for production quality control (B.5.1.1.1), 2) establish the median initial burst pressure, which is used for performance verification testing (B.5.1.2, B.5.1.3) and for production quality control (i.e., to assure conformity of production with properties of the qualification batch) (B.7.1.1.4), and 3) verify that the minimum burst pressure and number of pressure cycles before leak meet minimal requirements.

Initial burst pressure requirements differ from end-of-life burst pressure requirements that conclude the test sequences in B.5.1.2 and B.5.1.3. The initial burst pressure pertains to a new, unused vessel and the end-of-life burst pressure pertains to a vessel that has completed a series of performance tests (B.5.1.2 or B.5.1.3) that replicate conditions of worst-case usage and environmental exposure in a full service life. Since fatigue accumulates over usage and exposure conditions, it is expected that the end-of-life burst pressure (i.e. burst strength) could be lower than that of a new and unexposed vessel.

A.5.1.1.1 Rationale for B.5.1.1.1 Baseline Burst Pressure. , B.5.1.1.1 establishes the median initial burst pressure, BP_O, and verifies that initial burst pressures of systems in the qualification batch are within the range $BP_O \pm 10\%$. BPo is used as a reference point in performance verification (B.5.1.2.8, and B.5.1.3.5), verification of consistency of the qualification batch (B.7.1.1.3) and production quality control (conformity of production) (B.7.1.1.4). B.5.1.1.1 verifies that BP_O is greater than or equal to 200% NWP.

In addition to being a performance requirement, it is expected that satisfaction of this requirement will provide assurance to the testing facility of container stability before the qualification testing specified in B.5.1.2, B.5.1.3 and B.5.1.4 is undertaken.

A.5.1.1.2 Rationale for B.5.1.1.2 Baseline Pressure Cycle Life. The requirement specifies that three (3) randomly selected new containerss are to be hydraulically pressure cycled to 125% NWP without rupture for 22,000 cycles or until leak occurs. Leak may not occur within a specified number of pressure cycles, #Cycles.. The specification of #Cycles within the range

5500 – 11,000 is the responsibility of individual Contracting Parties. That is, the number of pressure cycles in which no leakage may occur, #Cycles, cannot be greater than 11,000, and it could be set by the Contracting Party at a lower number but not lower than 5,500 cycles for 15 years service life. The rationale for the numical values used in this specification follows:

A.5.1.1.2.a Rationale for "Leak Before Burst" Aspect of Baseline Pressure Cycle Life Requirements. The Baseline Pressure Cycle Life requirement verifies absence of rupture during 22,000 hydraulic pressure cycles. The probability of a rupture event is made lower than the probability of a leakage by requiring absence of rupture in at least twice as many hydraulic pressure test cycles. The risk (risk = (probability of event) x (severity of event)) of a leak event is comparable to that of rupture since the severity of a leak event is lower than the severity of a rupture event (fire risk without a damaging pressure release). Also, the likelihood of fire resulting from hydrogen leakage is mitigated by the high dispersion rate and buoyancy of hydrogen and because a hydrogen-fueled vehicle is equipped with hydrogen sensors that terminate vehicle operation when a leak is first detected (thereby ensuring timely repair).

The minimum number of pressure cycles without leakage, #Cycles (between 5500 and 11,000) is established to verify resistance to leakage (see A.1.1.1.2.b). 22,000 cycles provides additional assurance with respect to rupture. 22,000 empty-to-full fueling cycles is expected to be equivalent to over 10 million km (6 million mi) of driving (see discussion in A.5.1.1.2.b below). Absence of rupture in hydraulic pressure cycling is demonstrated under the most stressful pressure cycling condition, which is the empty-to-full fill (from less than 2 MPa to 125% NWP). (Note: a faster test time (lower number of pressure cycles until leakage occurs) could be achieved by cyclng to higher pressures but that could elicit failure modes that could not occur in real world service.)

A.5.1.1.2.b Rationale for #Cycles, Number of Hydraulic Pressure Cycles in Qualification Testing: #Cycles greater than or equal to 5500 and less than or equal to 11000. The number of hydraulic test pressure cycles is to be specified by individual Contracting Parties primarily because of differences in the expected worst-case lifetime vehicle range (distance driven during vehicle service life) and worst-case fueling frequency in different jurisdictions. The differences in the anticipated maximum number of fuelings are primarily associated with high usage commercial taxi applications, which can be subjected to very different operating constraints in different regulatory jurisdictions. For example:

1. Vehicle Fleet Odometer Data (including taxis): Sierra Research Report No. SR2004-09-04 for the California Air Resource Board (2004) reported on vehicle lifetime distance traveled by scrapped California vehicles, which all showed lifetime distances traveled below 560,000 km (350,000 mi). Based on these figures and 320 - 480 km (200 - 300 mi) driven per full fueling, the maximum number of lifetime empty-to-full fuelings can be estimated as 1200 - 1800.
2. Vehicle Fleet Odometer Data (including taxis): Transport Canada reported that required emissions testing in British Columbia, Canada, in 2009 showed the 5 most extreme usage vehicles had odometer readings in the 800,000 – 1,000,000 km (500,000 – 600,000 mi) range. Using the reported model year for each of these vehicles, this

corresponds to less than 300 full fuelings per year, or less than 1 full fueling per day. Based on these figures and 320 - 480 km (200 - 300 mi) driven per full fueling, the maximum number of empty-to-full fuelings can be estimated as 1650 - 3100.

3. Taxi Usage (Shifts/Day & Days/Week) Data: The New York City (NYC) Taxicab Fact Book (Schaller Consulting, 2006) reports extreme usage of 320 km (200 mi) in a shift and a maximum service life of 5 years. Less than 10% of vehicles remain in service as long as 5 years. The average mileage per year is 72,000 for vehicles operating 2 shifts per day and 7 days per week.
   There is no record of any vehicle remaining in high usage through-out the full 5 year service life. However, if a vehicle were projected to have fueled as often as 1.5 - 2 times per day and to have remained in service for the maximum 5-year NYC taxi service life, the maximum number of fuelings during the taxi service life would be 2750 - 3600 fuelings.
4. Taxi Usage (Shifts/Day & Days/Week) Data: Transport Canada reported a survey of taxis operating in Toronto and Ottawa that showed common high usage of 20 hours per day, 7 days per week with daily driving distances of 540 – 720 km (335 – 450 mi). Vehicle odometer readings were not reported. In the extreme worst-case, it might be projected that if a vehicle could remain at this high level of usage for 7 years (the maximum reported taxi service life); then a maximum extreme driving distance of 1,400,000 – 1,900,000 km (870,000 – 1,200,000 mi) is projected. Based on 320 - 480 km (200 - 300 mi) driven per full fueling, the projected full-usage 15-year number of full fuelings could be 2900 – 6000.

   Consistent with these extreme usage projections, the minimum number of full pressure hydraulic qualification test cycles for hydrogen storage systems is set at 5500. The upper limit on the number of full-fill pressure cycles is set at 11,000, which corresponds to a vehicle that remains in the high usage service of 2 full fueling per day for an entire service life of 15 years , the number of fuelings (lifetime vehicle mileage of 3.5 – 5.3 million km (2.2 – 3.3 million miles)). lifetime mileage.

In establishing #Cycles, it was recognized that some storage system designs (such as composite wrap systems with metal liner interiors) might not qualify for service at 70 MPa NWP if #Cycles is greater than 5500.

In establishing #Cycles, it was recognized that if #Cycles is specified at 5500, some Contracting Parties may require usage constraints to assure actual fuelings do not exceed #Cycles.

A.5.1.2 Rationale for B.5.1.2 Verification Test for On-Road Performance Durability (Hydraulic Sequential Tests). 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 damage and harsh environmental conditions. These durability tests focus on structural resistance to rupture. The additional 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 (leaks are mitigated by onboard leak detection linked to countermeasures). Since these extreme conditions are focused on structural stress and fatigue, they are conducted hydraulically – which allows more repetitions of stress exposure in a practical test time.

A.5.1.2.1 Assumptions used in developing the B.5.1.2 test protocol include:

a. Extended & severe service worst-case = lifetime of most stressful empty-to-full (125% NWP @ 85C, 80% @ -40C) fuelings under extended & severe usage; 10 service-station over-pressurization events
b. Sequential performance of tests replicates on-road experience where a single container is subject to multiple extremes of different exposure conditions – it is not realistic to expect that a container could only encounter one type of exposure through the life of the vehicle.
c. Severe usage: Exposure to physical impacts
   i. Drop impact (B.5.1.2.2) – the risk is primarily an aftermarket risk during 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 containers have the capability to survive representative pre-installation drop impacts.
   ii. Surface damage (B.5.1.2.3) – cuts characteristic of wear from mounting straps can wear through protective coatings
   iii. On-road impacts that degrade exterior structural strength and/or penetrate protective coatings (e.g., flying stone chips) (B.5.1.2.3) – simulated by pendulum impact.
d. Severe usage: Exposure to chemicals in the on-road environment (B.5.1.2.4)
   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 and gasoline).
   ii. The primary historical cause of rupture of high pressure vehicle containers (CNG containers), other than fire and physical damage, 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 containers 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.
e. Extreme Number of Fuelings/De-fuelings
   i. Rationale for #Cycles greater than 5500 and less than 11,000 is provided in A.5.1.1.2.b.
f. Extreme Pressure Conditions for fueling/de-fueling cycles (B.5.1.2.4)
   i. Fueling station over-pressurization constrained by fueling station requirements to less than or equal to 150% NWP. (This requirement for fueling stations must be established within local codes and/or regulations for fueling stations.)
   ii. Field data on the frequency of failures of high pressure fueling stations involving activation of pressure relief controls is not available. Experience with CNG

vehicles suggests overpressure by fueling stations has not contributed significant risk for container rupture.

iii. Assurance of capability to sustain multiple occurrences of over-pressurization due to fueling station failure is provided by the requirement to demonstrate absence of leak in 10 exposures to 150% NWP fueling followed by long-term leak-free parking and subsequent fueling/de-fueling.

g. Extreme environmental conditions for fueling/de-fueling cycles (B.5.1.2.6). Weather records show temperatures less than or equal to -40C occur in countries north of the 45-th parallel; temperatures ~50C occur in desert areas of lower latitude countries; each with frequency of sustained extreme temperature ~5% in areas with verifiable government records. [Actual data shows ~5% of days have a minimum temperature less than -30C. Therefore sustained exposure to less than -30C is less than 5% of vehicle life since a daily minimum is not reached for a full 24 hr period] Data record examples (Environment Canada 1971-2000):

   i. http://www.climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html?Province=ONT%20&StationName=&SearchType=&LocateBy=Province&Proximity=25&ProximityFrom=City&StationNumber=&IDType=MSC&CityName=&ParkName=&LatitudeDegrees=&LatitudeMinutes=&LongitudeDegrees=&LongitudeMinutes=&NormalsClass=A&SelNormals=&StnId=4157&
   ii. http://www.climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html?Province=YT%20%20&StationName=&SearchType=&LocateBy=Province&Proximity=25&ProximityFrom=City&StationNumber=&IDType=MSC&CityName=&ParkName=&LatitudeDegrees=&LatitudeMinutes=&LongitudeDegrees=&LongitudeMinutes=&NormalsClass=A&SelNormals=&StnId=1617&

h. Extended and Severe Usage: High Temperature Full-fill Parking up to 25 years (Prolonged Exposure to High Pressure) (B.5.1.2.5) To avoid a performance test lasting for 25 years, a time-accelerated performance test using increased pressure developed using experimental material data on currently used metals and composites, and selecting the worst-case for stress rupture susceptibility, which is glass fiber reinforced composite. Use of laboratory data to establish the equivalence of testing for stress rupture at 100% NWP for 25 years and testing at 125% NWP for 1000 hours (equal probability of failure from stress rupture) is described in SAE Technical Paper 2009-01-0012. Laboratory data on high pressure container composite strands – documentation of time-to-rupture as a function of static stress without exposure to corrosives – is summarized in Aerospace Corp Report No. ATR-92(2743)-1 (1991) and references therein.

   i. No formal data is available on parking duration per vehicle at different fill conditions. Examples of expected lengthy full fill occurrences include vehicles maintained by owners at near full fill conditions, abandoned vehicles and collectors' vehicles. Therefore, 25 years at full fill is taken as the test requirement.
   ii. The testing is performed at +85^{o}C because some composites exhibit an Arrhenius temperature-dependent fatigue rate (potentially associated with resin oxidation) (J. Composite Materials 11, 79 (1977)). 85^{o}C is selected as the maximum potential exposure temperature because under-hood maximum temperatures of +82 °C have been measured within a dark-colored vehicle parked outside on asphalt in direct sunlight in 50^{o}C ambient conditions. Also, a compressed gas container, painted black, with no cover, in the box of a black pickup truck in direct sunlight in 49 °C

had maximum / average measured container skin surface temperatures of 87 °C (189 °F) / 70 °C (159 °F).

iii. On-road experience with CNG containers –there has not been a report of an on-road stress rupture without exposure to corrosives (stress corrosion cracking) or design anomaly (hoop wrap tensioned for liner compression without autofrettage). B.5.1.2 testing that includes chemical exposure test and 1000 hours of static full pressure exposure simulates these failure conditions.

i. Residual Proof Pressure (B.5.1.2.7)
   i. Fueling station over-pressurization constrained by fueling station requirements to less than or equal to 150% NWP. (This requirement for fueling stations must be established within local codes/regulations for fueling stations.)
   ii. 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 as the worst case (SAE Technical Report 2009-01-0012). Fueling stations are expected to provide over-pressure protection up to 150% NWP.
   iii. Testing at "end-of-life" provides assurance to sustain fueling station failure throughout service.

j. Residual Strength Burst (B.5.1.2.8)
   Requirement for a less than 20% decline in burst pressure after 1000-hr static pressure exposure is linked (in SAE Technical Report 2009-01-0012) to assurance that requirement has allowance for $\underline{+}$10% manufacturing variability in assurance of 25 years of rupture resistance at 100% NWP.

k. Rationale for not including a boss torque test requirement: Note that damage to containers caused by maintenance errors is not included because maintenance errors, such as boss over torquing, are addressed by maintenance training procedures and tools and fail safe designs. Similarly damage to containers caused by malicious and intentional tampering is not included.

A.5.1.3 Rationale for B.5.1.3 Verification Test for Expected On-road Performance (Pneumatic sequential tests). 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), 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 cumulative impact is required for the safe performance of all vehicles in expected service.

Pneumatic testing with hydrogen gas provides stress factors associated with rapid and simultaneous interior pressure and temperature swings and infusion of hydrogen into materials; therefore, pneumatic testing is focused on the container interior and strongly linked to the initiation of leakage. Failure by leakage is marginally mitigated by secondary protection – monitoring and vehicle shut down when warranted (below a conservative level of flammability risk in a garage), which is expected to result in very timely repair before leakage can develop further since the vehicle will be out of service.

Data used in developing the B.5.1.3 test protocol include:

a. Proof Pressure Test (B.5.1.3.1) – routine production of pressure containers includes a verifying, or proof, pressure test at the point of production, which is 150% NWP as industry practice, i.e. 20% above the maximum service pressure.

b. Leak-Free Fueling Performance (B.5.1.3.2)

   i. Expected environmental conditions -- weather records show temperatures less than or equal to -40C occur in countries north of the 45-th parallel; temperatures ~50C occur in desert areas of lower latitude countries; each with frequency of sustained extreme temperature ~5% in areas with verifiable government records. [Actual data shows ~5% of days have a minimum temperature below -30C. Therefore sustained exposure to below -30C is less than 5% of vehicle life since a daily minimum is not reached for a full 24 hr period] Data record examples (Environment Canada 1971-2000):

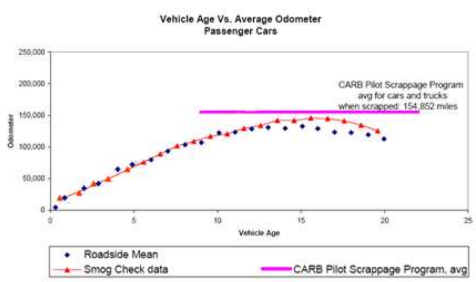
      (a) http://www.climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html?Province=ONT%20&StationName=&SearchType=&LocateBy=Province&Proximity=25&ProximityFrom=City&StationNumber=&IDType=MSC&CityName=&ParkName=&LatitudeDegrees=&LatitudeMinutes=&LongitudeDegrees=&LongitudeMinutes=&NormalsClass=A&SelNormals=&StnId=4157&

      (b) http://www.climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html?Province=YT%20%20&StationName=&SearchType=&LocateBy=Province&Proximity=25&ProximityFrom=City&StationNumber=&IDType=MSC&CityName=&ParkName=&LatitudeDegrees=&LatitudeMinutes=&LongitudeDegrees=&LongitudeMinutes=&NormalsClass=A&SelNormals=&StnId=1617&

   ii. Number of fueling/de-fueling cycles

      (a) The number of full fuelings required to demonstrate capability for leak-free performance in expected service is taken to be 500

         (1) Expected vehicle lifetime range is taken to be 250000 km (155000 mi)



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.

         (2) Expected vehicle range per full fueling is taken to be greater than or equal to 500km (300 mi) (based on 2006-2007 market data of high volume passenger vehicle manufacturers in Europe, Japan and North America).

(3) 500 cycles = 250000/500 ~ 155000miles / 300miles-per-cycle

(4) Some vehicles may have shorter driving ranges per full fueling, and may achieve more than 500 full fuelings if no partial fuelings occur in the vehicle life. Demonstrated capability to perform without leak in 500 full fuelings is intended to establish fundamental suitability for on-road service -- leakage is subject to secondary mitigation by detection and vehicle shut-down before safety risk develops.

(5) Since the stress of full fuelings exceeds the stress of partial fuelings, the design verification test provides a significant margin of additional robustness for demonstration of leak-free fueling/de-fueling capability.

(b) Qualification requirement of 500 pneumatic pressure cycles is conservative when considering failure experience:

(1) On-road experience: 70MPa hydrogen storage systems have developed leaks in o-ring sealings during brief (less than 50 full fuelings) on-road service of demonstration prototype vehicles.

(2) On-road experience: 70 MPa hydrogen storage systems have developed temporary (subsequently resealing) leaks during brief (less than 50 full fuelings) on-road service of demonstration prototype vehicles.

(3) On-road experience: mechanical failures of CNG vehicle storage associated with gas intrusion into wrap/liner and interlaminate interfaces have developed after brief on-road service (less than 50 full fuelings).

(4) On-road experience: failure of CNG vehicle storage due to interior charge build-up and liner damage corona discharge is not a failure mode because static charge is carried into containers on particulate fuel impurities and ISO 14687-2 (and SAE J2719) fuel requirements limit particulates in hydrogen fuel -- also, fuel cell power systems are not tolerant of particulate impurities and are expected to cause vehicles to be out of service if inappropriate fuel is dispensed.

(5) Test experience: mechanical failures of vehicle storage systems associated with gas intrusion into wrap/liner and interlaminate interfaces develop in ~ 50 full fuelings.

(6) Test experience: 70MPa hydrogen storage systems that passed NGV2 test requirements have failed during the B.5.1.3 test conditions in failure modes that would be expected to occur in on-road service (Powertech report to DOE/SAE, 2009). The Powertech report cites two failures of systems with containers that have qualified for service: metal-lined composite container valve leak and in-container solenoid leak, polymer-lined composite container leak due to liner failure. The polymer-lined composite container failure by leakage was on a container that was qualified to ANSI/CSA NGV2 modified for hydrogen. The metal-lined composite failure of the container valve was on a valve qualified to EIHP rev12b. Report conclusion: “The test sequences in SAE TIR J2579 have shown that containers with no known failures in service either met the requirements of the tests, or

fail for reasons that are understood and are representative of future service conditions"

iii. Fueling conditions

(a) SAE J2601 establishes fueling protocol -- 3 minutes is fastest empty-to-full fueling (compatible with typical gasoline fueling; existing in installed state-of-art hydrogen fueling stations); fuel temperature for fast fueling is ~ -40^{o}C.

(b) Expected maximum thermal shock conditions are for a system equilibrated at an environmental temperature of ~50^{o}C subjected to -40^{o}C fuel, and for a system equilibrated at -40^{o}C subjected to indoor private fueling at approximately +20^{o}C.

(c) Fueling stresses are interspersed with parking stresses.

c. Leak-free Parking at full fill (B.5.1.3.3)

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

ii. The leak/permeation limit is characterised by the many possible combinations of vehicle and garages, and the associated test conditions. The leak/permeation limit is defined to restrict the hydrogen concentration from reaching 25% LFL by volume with worst credible conditions of a tight, very hot (55^{o}C) garage having a low air exchange rate (0.03 volumetric air exchanges per hour). The conservative 25% LFL limit is conventionally adopted to accommodate concentration inhomogeneities. Data for hydrogen dispersion behaviour, garage and vehicle scenarios, including garage sizes, air exchange rates and temperatures, and the calculation methodology are found in the following reference prepared as part of the EC Network of Excellence (NoE) HySafe: P. Adams, A. Bengaouer, B. Cariteau, V. Molkov, A.G. Venetsanos, "Allowable hydrogen permeation rate from road vehicles", Int. Jour. of Hydrogen Energy, Available online 8 June 2010, ISSN 0360-3199, DOI: 10.1016/j.ijhydene.2010.04.161. (http://www.sciencedirect.com/science/article/B6V3F-50867HJ-4/2/3c599afa202ac7970eafc5caa93ca09e).

iii. The resulting discharge limit measured at 55^{0}C and 115% NWP (full fill at 55^{0}C) following specified pneumatic pressure cycling of the storage system is scalable depending on the vehicle size around a nominal value of 150 mL/min for a garage size of 30.4 m^3. The scaling factor, [(Vwidth+1)*(Vheight+0.05)*(Vlength+1)/ 30.4] accommodates alternative garage/vehicle combinations to those used in the derivation of the rate, and accommodates small vehicles that could be parked in smaller garages. These vehicle level permeation requirements are consistent with the proposals developed by the EU NoE HySafe, see above reference. The permeation values measured for individual storage container systems used in a vehicle would sum to less than the vehicle limit.

iv. An alternative discharge limit is provided for ease of compliance testing for some systems, which is also consistent with the proposals developed by the EU NoE HySafe. In this case, the permeation limit measured at 55^{0}C and 115% NWP is 46 mL/h/L water capacity of the storage system and the total water capacity of the vehicle storage system shall be less than 330 L.

v. The maximum pressure of a fully filled container at 55C is 115% NWP (equivalent state of charge to 125% NWP at 85C and 100% NWP at 20C).

vi. 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 criterion is selected as 0.005 mg/sec.

vii. Parking provides opportunity for hydrogen saturation of interlaminate layers, wrap/liner interface, liner materials, junctures, o-rings, and joinings – fueling stresses are applied with and without exposure to hydrogen saturation. Hydrogen saturation is marked by permeation reaching steady-state rate.

viii. By requiring qualification under the worst credible case conditions of raised temperature, pressure cycling and equilibration with hydrogen, the permeation verification removes uncertainty about permeation/temperature dependence, and long term deterioration with time and usage.

d. Residual Proof Pressure (B.5.1.3.4)

i. Fueling station over-pressurization constrained by fueling station requirements to less than 150% NWP. (This requirement for fueling stations must be established within local codes/regulations for fueling stations.)

ii. 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). Fueling stations are expected to protect against over-pressure over 150% NWP.

iii. 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.

e. Residual Strength Burst (B.5.1.3.5)

Requirement for less than 20% decline in burst pressure after lifetime service is designed to ensure stability of structural components responsible for rupture resistance; it is linked (in SAE 2009-01-0012) to assurance that requirement has allowance for 10% manufacturing variability in assurance of greater than 25 years of rupture resistance at 100% NWP in B.5.1.2.5.

It is expected that regulatory agencies and manufacturers will monitor the condition and performance of storage systems during service life as practical and appropriate to continually verify that B.5.1.3 performance requirements capture on-road requirements. This advisory is meant to encourage manufacturers and regulatory agencies to collect additional data.

A.5.1.4 Rationale for B.5.1.4 Verification Test for Service Terminating Performance

Verification of performance under service terminating conditions is designed to prevent the severe impact of rupture under conditions so severe that hydrogen containment cannot be maintained. Fire is the service terminating condition accounted for in design qualification

⇒⇒SGS-10: US/participants will provide rationale for fire tests

⇒⇒SGS-10: Comments on fire tests are requested; type of fuel, type of burners and others

A.5.1.5 Rationale for B.5.1.5 Labeling. The purpose of minimum labeling on the hydrogen storage containers is three-fold: 1) To document the date when the system should be removed from service, 2) To record information needed to trace manufacturing conditions in event of on-road failure, and 3) To document NWP to ensure installation is consistent with the vehicle fuel system and fueling interface.

A.5.2 LIQUIFIED HYDROGEN STORAGE SYSTEM TEST REQUIREMENTS & SAFETY CONCERNS

The containment of the hydrogen within the liquefied hydrogen storage system is essential to successfully isolating the hydrogen from the surroundings and down-stream systems. The system-level performance tests in Section B.5.2 were developed to demonstrate a sufficient safety level against burst of the container and capability to perform critical functions throughout service including pressure cycles during normal service, pressure limitation under extreme conditions and faults, and in fires.

Performance test requirements for all liquefied hydrogen storage systems in on-road vehicle service are specified in Section B 5.2. These criteria apply to qualification of storage systems for use in new vehicle production.

This Section (A.5.2) specifies the rationale for the performance requirements established in Section B.5.2 for the integrity of the liquefied hydrogen storage system. Manufacturers are expected to ensure that all production units meet the requirements of performance verification testing in Section B.5.2.1 to 5.2.4.

A.5.2.1 Rationale for B.5.2.1 Verification Tests for Baseline Metrics

A proof pressure test and a baseline initial burst test are intended to demonstrate the structural capability of the inner container.

A.5.2.1.1 Rationale for B.5.2.1.1 Proof Pressure Test

By design of the container and specification of the pressure limits during regular operation and during fault management (as demonstrated in B5.2.3.2 und B.5.2.3.3), the pressure in the inner container could rise to 110% of the Maximum Allowable Working Pressure (MAWP) during fault management by the primary pressure relief device and no higher than 150% of MAWP even in “worst case” fault management situations where the primary relief device has failed and the secondary pressure relief device is required to activate and protect the system. The purpose of the proof test to 130 per cent MAWP is to demonstrate that the inner container stays below its yield strength at that pressure.

A.5.2.1.2 Rationale for B.5.2.1.2 Baseline Initial Burst Pressure

By design (and as demonstrated in B5.2.3.3), the pressure may rise up to 150% of the Maximum Allowable Working Pressure (MAWP) when the secondary (backup) pressure relief device(s) may be required to activate. The burst test is intended to demonstrate margin against burst during this “worst case” situation. The pressure test levels of either the Maximum Allowable Working Pressure (in MPa) plus 0.1 MPa multiplied by 3.25 or the Maximum Allowable Working Pressure (MAWP) (in MPa) plus 0.1 MPa multiplied by 1.5 and multiplied by Rm/Rp (where Rm is ultimate tensile strength and Rp is minimum yield strength of the container material) are common values to provide such margin for metallic liners.

Additionally, the high burst test values (when combined with proper selection of materials in B5.2.2) demonstrate that the stress levels are acceptably low such that cycle fatigue issues are unlikely for metallic containers that have supporting design calculations. In the case of non-metallic containers, an additional test is defined in 7.2.1 to demonstrate this capability as the calculation procedures have not yet been standardized by for these materials.

A.5.2.2 Rationale for B.5.2.2 Verification for Material Compatibility

Proper selection of materials for exposure to hydrogen at extremely low temperatures is required to ensure that materials will not show hydrogen embrittlement or otherwise degrade during expected operation. The test methods in B.5.2.2 reflect an internationally accepted approach to evaluate material compatibility.

A.5.2.3 Rationale for B.5.2.3 Verification for Expected On-road Performance.

A.5.2.3.1 Rationale for B5.2.3.1 Boil-off Test

During normal operation the boil-off management system shall limit the pressure below MAWP. The most critical condition for the boil-off management system is a parking period after a refueling to maximum filling level in a liquefied hydrogen storage system with a limited cool-down period of maximum 48 hours.

A.5.2.3.2 Rationale for B.5.2.3.2 Hydrogen Discharge Test

The Hydrogen discharge test shall be conducted during Boil-off of the liquid storage system. Manufacturers will typically elect to react all (or most) of the hydrogen that leaves the container, but, in order to have a hydrogen discharge criteria that is comparable to the values used for Compressed Hydrogen Storage Systems, it is to include any hydrogen that leaves the vehicle boil-off systems with other leakage, if any, to determine the total hydrogen discharge from the vehicles.

Having made this adjustment, the total hydrogen discharge from a vehicle with liquefied hydrogen storage is the same as a vehicle with compressed hydrogen storage system. According to the discussion in B.5.1.3, the total discharge from a vehicle with liquefied hydrogen may therefore be 150 mL/min for a garage size of 30.4 m^3. As with compressed gas, the scaling factor, [(Vwidth+1)*(Vheight+0.05)*(Vlength+1)/ 30.4], can be used to accommodate alternative garage/vehicle combinations to those used in the derivation of the rate, and accommodates small vehicles that could be parked in smaller garages.

Prior to conducting this test, the primary pressure relief device should be forced to activate so that the ability of the primary relief device to re-close and meet required leakage is confirmed.

A.5.2.3.3 Rationale for B.5.2.3.1 Vacuum Loss Test

In order to prove the proper function of the pressure relief devices and the compliance with the allowed pressure limits of the liquefied hydrogen storage system as described in A5.2.1 and verified in B.5.2.1, a sudden vacuum loss due to air inflow in the vacuum jacket is considered as the “worst case” failure condition. In contrast to hydrogen inflow to the vacuum jacket, air inflow causes significantly higher heat input to the inner container due to condensation of air at cold surfaces and evaporation of air at warm surfaces within the vacuum jacket.

The primary pressure relief device should be a re-closing type relief valve so that hydrogen venting will cease when the effect of a fault subsides. These valves, by globally-accepted design standards, are allowed a total pressure increase of 10% between the setpoint and full activation when including allowable tolerances of the setpoint setting itself. Since the relief valve should be set at or below the MAWP, the pressure during a simulation of the fault that is managed by the primary pressure relief device should not exceed 110% of Maximum Allowable Working Pressure (MAWP).

The secondary pressure relief device(s) should not activate during the simulation of a vacuum loss that is managed by the primary relief device as their activation may cause unnecessary instability and unnecessary wear on the secondary devices. To prove fail-safe operation of the pressure relief devices and the performance of the second pressure relief device in accordance with the requirements in B.5.2.3.3 a second test shall be conducted with the first pressure relief device blocked. In this case, either relief valves or burst discs may be used, and the pressure is allowed to rise to as high as 136 per cent MAWP (in case of a valve used as secondary relief device) or as high as 150 per cent MAWP (in case of a burst disc used as secondary relief device) during the simulation of a vacuum loss fault.

A.5.2.4. Rationale for B.5.2.4 Verification Test for Service Terminating Conditions

In addition to vacuum degradation or vacuum loss fire also may cause overpressure in liquefied hydrogen storage systems and thus proper operation of the pressure relief devices and the requirements described in Section A.5.2.3.3 have to be proven in a bonfire test

A.5.3. VEHICLE FUEL SYSTEM REQUIREMENTS & SAFETY CONCERNS

A.5.3.1 IN-USE REQUIREMENTS

A.5.3.1.1. Rationale for B.5.3.1.1. Fueling Port. The vehicle fueling receptacle should be designed to ensure the fueling pressure is appropriate for the vehicle fuel storage system. Examples of receptacle designs can be found in ISO 17268, SAE J2600 and SAE J2799. A label shall be affixed to the fueling port to inform the fueler/driver/owner of the type of fuel (liquid or gaseous **h**ydrogen), NWP and date for removal of storage containers from service.

A.5.3.1.2 Rationale for B.5.3.1.2 Hydrogen Discharge System

A.5.3.1.2.1 Rationale for B.5.3.1.2.1 Pressure relief systems. The vent line of storage system discharge systems (TPRDs and PRDs) should be protected by a cap to prevent blockage by intrusion of objects such as dirt, stones, and freezing water.

A.5.3.1.2.1 Rationale for B.5.3.1.2 Fuel cell / engine exhaust systems. In order to ensure that the exhaust discharge from the vehicle is non-hazardous a performance-based tests is defined to demonstrate that the discharge is non-ignitable.
The 3 second rolling-average accommodates extremely short, non-hazardous transients up to 8% without allowing ignition. Tests of flowing discharges have shown that propagation from the ignition source readily occurs above 10% hydrogen, but does not propagate below 8% hydrogen. (SAE Technical Paper 2007-01-437 „Development of Safety Criteria for Potentially Flammable Discharges from Hydrogen Fuel Cell Vehicles" (2007 SAE World Congress)). By limiting the hydrogen content of any instantaneous peak to 8%, the hazard to people near the point of discharge is controlled even if an ignition source is present. The time period of the rolling-average is determined to ensure that the space around the vehicle remains non-hazardous as the hydrogen from exhaust diffuses into the surroundings; this is the case of a idling vehicle in a closed garage. In order to readily gain acceptance for this situation by building officials and safety experts, it should be recognized that government/municipal building codes and internationally-recognized standards such as IEC 60079 require that the space be less than 25% LFL (or 1% hydrogen) by volume. The time limit for the rolling-average was determined by assuming an extremely high hydrogen discharge rate that is equivalent to the input to a 100 kW fuel cell stack. The time was then calculated for this hydrogen discharge to fill the nominal space occupied by a passenger vehicle (4.6m x 2.6m x 2.6m) to 25% LFL. The resultant time limit was conservatively estimated to be 8 seconds for a "rolling average", demonstrating that the 3-second used in this document is appropriate and accommodates variations in garage and engine size. The standard ISO instrumentation requirement is a factor of 6-10 of the measured value. Therefore, during the test procedure according to B.6.1.4, the 3-second rolling average requires a sensor response (90% of reading) and recording rate of less than 300 milliseconds.

A.5.3.1.3 Rationale for B.5.3.1.3 Protection against flammable conditions: Single Failure Conditions . Dangerous situations can occur if unintended leakage of hydrogen reaches flammable concentrations.

a. The on-board hydrogen container should be equipped with a shut off valve that can be automatically activated.

b. Protection against the occurrence of 4% by volume hydrogen in air (or greater) in the passenger compartment, luggage compartment, and spaces within the vehicle that contain unprotected ignition sources is important.
   - Vehicles may achieve this objective by design (for example, where spaces are vented to prevent increasing hydrogen concentrations).
   - If the vehicle achieves this objective by detection of hydrogen concentrations in air of 4% or greater, then the main hydrogen shutoff valve(s) shall immediately 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.

A.5.3.1.4 Rationale for B.5.3.1.4. Fuel leakage. Leakage is not permitted.

A.5.3.1.5 Rationale for B.5.3.1.5 Tell-Tale. A telltale/warning system is to alert the driver when hydrogen leakage results in concentration levels at or above 4% by volume within the passenger compartment, luggage compartment, and spaces with unprotected ignition sources within the vehicle. The telltale should also alert the driver in case of a malfunction of the hydrogen detection system. Furthermore, the system shall be able to respond to 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. There is no data available to suggest that the warning function of the telltale would be diminished if it is only visual. In case of the detection system failure, the telltale warning light should be yellow. In case of the emergency shut-off of the valve, the telltale light should be red.

A.5.3.1.6 Lower Flammability Limit (LFL) (Background for B.3.9): Lowest concentration of fuel in which a gas mixture is flammable. National and international standard bodies (such as NFPA and IEC) recognize 4% hydrogen by volume in air as the LFL. (US Department of Interior, Bureau of Mines Bulletin 503, 1952; Int J of Hydrogen Energy 3, 136 2007; NASA RD-WSTF-0001, 1988) for further information. The Lower Flammability Limit (LFL) depends on mixture temperature, pressure and the presence of dilution gases, has been assessed using specific test methods (e.g., ASTM E681-04). While the LFL value of 4% is appropriate for evaluating flammability in general surroundings of vehicles or inside passenger compartments, this criterion 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. [Coward, H.F. et al, “Limits of flammability of gases and vapors”, Bureau of Mines Bulletin 503; 1952, USA; Benz, F.J. et al, “Ignition and thermal hazards of selected aerospace fluids”, RD-WSTF-0001, NASA Johnson Space Center White Sands Test Facility, Las Cruces, NM, USA, October 1988; Houf, W.G. et al, „Predicting radiative heat fluxes and flammability envelopes from unintended releases of hydrogen“, International journal of Hydrogen Energy, e, pp136-141, 2007]

A.5.3.1.7 Recommended features for design of a hydrogen fuel system.

As any performance based technical regulation cannot include testing requirements for every possible scenario, this section is to provide manufacturers a list of items that they should consider during the design of hydrogen fuelling systems with the intention to reduce hydrogen leaks and provide a safe product.

a. It should function in a safe and proper manner and be designed to minimize the potential for hydrogen leaks, (e.g. the minimize line connections to the extent possible).
b. It should reliably withstand the chemical, electrical, mechanical and thermal service conditions that may be found during normal vehicle operation.
c. The materials used should be compatible with gaseous or liquid hydrogen as appropriate
d. The hydrogen fuel system should be installed such that it is protected against damage under normal operating conditions.
e. Rigid fuel lines should be secured such that they shall not be subjected to critical vibration or other stresses.
f. It should protect against excess flow in the event of a failure downstream of the fueling system.
g. No component of the hydrogen fuel system, including any protective materials that form part of such components, should project beyond the outline of the vehicle or protective structure.

A.5.3.2 POST CRASH REQUIREMENTS

A.5.3.2.1 Rationale for B.5.3.2.1 Post-Crash Test Leakage Limit

The allowable post-crash leakage in FMVSS 301 (for the USA) and ECE 94 and 95 are within 6% of each other for the 60 minute period after the crash. Since the values are quite similar, the value in ECE 94 and 95 of 30g/min was selected as a basis of the calculations to establish the post-crash allowable hydrogen leakage for this document.

The criterion for post-crash hydrogen leakage is based on allowing an equivalent release of combustion energy as permitted by gasoline vehicles. Using a lower heating value of 120 MJ/kg for hydrogen and 42.7 MJ/kg for gasoline based on the US DOE Transportation Data Book, the equivalent allowable leakage of hydrogen can be determined as follows:

$$W_H = 30\,\mathrm{g/min} \times \frac{42.7\,\mathrm{MJ/kg}}{120\,\mathrm{MJ/kg}} = 10.7\,\mathrm{g/min}$$

for vehicles with either Compressed Hydrogen Storage Systems (CHSSs) or Liquefied Hydrogen Storage Systems (LHSSs). The total allowable loss of hydrogen is therefore 642g for the 60 minute period following the crash.

The allowable hydrogen flow leakage can also be expressed in volumetric terms at normal temperature (0^{o}C) and pressure as follows:

$$V_H = \frac{10.7\ \text{g/min}}{2\,(1.00794)\ \text{g/mol}}\ \text{x}\ 22.41\ \text{NL/mol} = 118\text{NL/min}$$

for vehicles with either CHSSs or LHSSs.

As confirmation of the hydrogen leak rate, JARI conducted ignition tests of hydrogen leaks ranging from 131 NL/min up to 1000 NL/min under a vehicle and inside the engine compartment. Results showed that, while a loud noise can be expected from ignition of the hydrogen, the sound pressure level and heat flux were not enough (even at a 1000 NL/min leak rate) to damage the under floor area of the vehicle, release the vehicle hood, or injure a person standing 1 m from the vehicle (SAE Technical Paper 2007-01-0428 "Diffusion and Ignition Behavior on the Assumption of Hydrogen Leakage from a Hydrogen-Fueled Vehicle").

A.5.3.2.2 Rationale for B.5.3.2.2 Post-Crash Concentration Limit in Enclosed Spaces This test requirement has been established to ensure that hydrogen does not accumulate in the passenger, luggage, or cargo compartments that could potentially pose a post-crash hazard. The criteria was conservatively set to 4% hydrogen by volume as value represents the lowest possible level that combustion can occur (and the combustion is extremely weak at this value). Since the test is conducted in parallel with the post-crash leak test and therefore will extend for at least 60 minutes, there is no need to provide margin on the criteria to manage dilution zones as there is sufficient time for the hydrogen to diffuse throughout the compartment.

A.5.4. ELECTRIC SAFETY REQUIREMENTS & SAFETY CONCERNS

Purpose: This section will specify the ELSA requirements for vehicle's high voltage system.

A.5.4.1 In-Use Requirements

A.5.4.2 Post-Crash Requirements

⇒⇒ Insert Rationale from ELSA

A.6 RATIONALE FOR B.6 TEST PROCEDURES

Test procedures in B.6 for replicate on-road conditions for performance requirements specified in B.5.1, 5.5.2 and B.5.3. Most individual test procedures and testing steps within test sequences in B.5.1 and B.5.2 derive from historical national regulations and/or industry standards.

⇒⇒ USA to draft rationale for fire test procedure

A.6.1 Rationale for B.6.1 Post-crash

A.6.1.1 Rationale for B.6.1.1 Test Procedure for Post-Crash Leak

The post-crash leak test is organized as follows:

- B.6.1.1.1 Post-crash leak test for compressed hydrogen storage systems
  - B.6.1.1.1.1 Test procedure when the test gas is hydrogen
  - B.6.1.1.1.2 Test procedure when the test gas is helium
- B.6.1.1.2 Post-crash leak test for liquid hydrogen storage systems

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A.6.1.1.1. Rationale for B.6.1.1.1 Post-crash leak test procedure for Compressed Hydrogen Storage Systems (CHSSs). The loss of fuel represents the allowable release for the entire compressed hydrogen storage system on the vehicle. The post-crash release can be determined by measuring the pressure loss of the compressed storage system over a time period of at least 60 minutes after the crash and then calculating the release rate of hydrogen based on the measured pressure loss and the time period using the equation of state of the compressed gas in the CHSS. (See the SAE Technical Paper 2010-10B-0164, "Development of the Methodology for FCV Post-crash Fuel Leak Testing in Corporated into SAE J2578 for a complete discussion of the methodology.) In the case of multiple hydrogen storage containers that are isolated from each other after crash, it may be necessary to measure hydrogen loss individually (using the approach in B5.3.2.1) and then sum the individual values to determine the total release of hydrogen gas from the strorage system.

The methodology can also be expanded to allow the use of a non-flammable gas for crash testing. Helium has been selected as it, like hydrogen, has low molecular weight. In order to determine the ratio of volumetric flows between helium and hydrogen releases (and thus establish a required relationship between hydrogen and helium leakage, we assume that leakage from the compressed hydrogen storage system can be described as choked flow through an orifice where the orifice area (A) represents the total equivalent leakage area for the post-crash system. In this case the equation for mass flow is given by

$$W = C \times Cd \times A \times (\rho \times P)^{1/2}$$

where Cd is the orifice discharge coefficient, A is the orifice area, P are the upstream (stagnation) fluid density and pressure, and ρ and C are given by

$$\rho = R_u \times T / M$$

and

$$C = \gamma /((\gamma + 1)/2)^{(\gamma+1)/(\gamma-1)}$$

where R_u is the universal gas constant and T, M, and γ are the temperature, molecular weight, and ratio of specific heats (C_V/C_P) for the particular gas that is leaking. Since Cd, A, R_u, T, and P are all constant for the situation of determining the relationship between post-crash helium and hydrogen leakage, the following equation describes the flow ratio on a mass basis.

$$W_{H2} / W_{He} = C_{H2} / C_{He} \times (M_{H2} / M_{He})^{1/2}$$

Since we can determine the volumtric flow ratio by multiplying the mass flow ratio by the ratio of molcular weights (M) at constant temperature and pressure conditions are the same.

$$V_{H2} / V_{He} = C_{H2} / C_{He} \times (M_{He} / M_{H2})^{1/2}$$

Based on the above relationship, it is possible to determine that the ratio of the volumtric flow (and therefore the ratio gas concentration by volume) between helium test gas and hydrogen is approximately 75% for the same leak passages from the CHSS. Thus, the post-crash hydrogen leakage can be determined by

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

where V_{He} is the post-crash helium leakage (NL/min).

A.6.1.1.2 Rationale for B.6.1.1.2 Post-Crash Leak Test -- Liquefied Hydrogen Storage Systems (LHSSs)

The purpose of the test is to confirm that the leakage from vehicles with LHSSs following the crash test. Visual detection of unacceptable leakage should be feasible. When using standard leak-test fluid, the bubble size is expected to be approximately 1.5 mm in diameter. For a localized rate of 0.005 mg/sec (3.6 mL/min), 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 would be approximately 32 bubbles per minute, thus producing a very conservative criteria if all the joints and vulnerable parts all accessible for post-crash inspection.

If the bubble test is not possible or desired, an overall leakage test may be conducted to produce a more objective result. In this case, the leakage criteria is the same as that developed for vehicles with Compressed Hydrogen Storage Systems (CHSSs). Specifically, the allowable hydrogen leakage from the LHSS is 118 NL/min or 10.7 g/min.The state of flow leaking from the LHSS may be gaseous, liquid, or a two-phase mixture of both. The leakage is expected to be in the gaseous state as the piping and shutoff valves downstream of the container are more vulnerable to crash damage that the highly insulated, double-walled LHSS container. None the less, the helium test prescribed in this document can detect very small leak sites and thus demonstrate the acceptability even if the leakage in the liqued state. It is not necessary to address the possiblity of a two-phase leak as the flow rate will be less than that can occur in the liquid state.

The helium leak test is conducted at room temperature with the LHSS pressurized with helium to normal operating pressure. The pressure level should be below the activation pressure of the pressure regulators and the Pressure Relief Devices (PRDs). If is expected that the helium test pressure can be conducted at approximately 80% of the Maximum Allowable Working Pressure (MAWP).

Leakage of hydrogen in the liquid state of an operating system is given by

$$W_l = C_d \times A \times (2 \times \rho_l \times \Delta P_l)^{1/2} \qquad \textit{Equation 1}$$

where W_l is the mass flow, C_d is the discharge coefficient, A is the area of the hole, ρ is the density, and ΔP_l is the pressure drop between the operating system and atmosphere. This equation is for incompressible fluids such as fluids in the liquid state. Use of this equation is very conservative for this situation as a portion of the fluid often flashes (that is, changes to a gaseous state) as the fluid passes through the leakage hole, causing a reduction in density and therefore a reduction in the mass flow.

The leakage of helium gas during the leak test is given by

$$W_{He} = C \times C_d \times A \times (\rho_{He} \times P_{He})^{1/2} \qquad \textit{Equation 2}$$

where C_d and A are as defined above, ρ and P are the upstream (stagnation) fluid density and pressure in the LHSS. C is given by

$$C = \gamma /((\gamma + 1)/2)^{(\gamma+1)/(\gamma-1)} \qquad \textit{Equation 3}$$

where γ is the ratio of specific heats for the helium gas that is leaking.

Since C_d and A are constants with the same values for both liquid hydrogen leaking from the operating LHSS and helium gas during the leak test, the ratio of helium to liquid hydrogen leakage can be calculated by

$$W_{He} / W_l = C_{He} \times (\rho_{He} / \rho_l)^{1/2} \times (P_{He} /(2 \times \Delta P_l))^{1/2} \qquad \textit{Equation 4}$$

based on combining *Equations 1 and 2*. *Equation 4* can be used to calculate the helium mass flow at the beginning of the pressure test, but the pressure will fall during the pressure test where as the pressure of the operating LHSS will remain approximately constant until all the liquid has been vented.

In order to accurately determine the allowable reduction in pressure during the leak test, the change in helium flow with pressure needs to be accounted for. Since the density of helium (ρ_{He}) varies with pressure, the mass flow of helium during the pressure test will also vary linearly with pressure as given by

$$W_t = P_t \times (W_{He} / P_{He}) \qquad \textit{Equation 5}$$

where W_t and P_t are the helium mass flow and pressure during the pressure test and W_{He} and P_{He} are the initial values of leak test.

Starting with the ideal gas law,

$$P_t V=M_t \times R_g \times T \qquad \textit{Equation 6}$$

where P_t is the test pressure, V is the volume of the LHSS, M_t is mass of the LHSS, R_g is the helium gas constant on a mass basis, and T is the temperature of the LHSS. Differentiating *Equation 6* with time leads to

$$\partial P_t/\partial t = R_g \times T / V \times \partial M_t/\partial t \qquad \textit{Equation 7}$$

where $\partial P_t/\partial t$ is the change in pressure during the helium pressure test. Since the change in mass within the LHSS ($\partial M_t/\partial t$) is equal to the helium mass flow during the test period (W_t), *Equation 5* for W_t can be substituted into *Equation 7*. After re-arranging terms, the equation becomes

$$\partial P_t / P_t = R_g \times T / V \times (W_{He} / P_{He}) \times \partial t = (W_{He} / M_{He}) \times \partial t \qquad \textit{Equation 8}$$

where M_{He} is the initial mass of helium in the LHSS for the pressure test.

Integrating the above differential equation results in expressions for the allowable pressure at the end of the helium leak test and the corresponding allowable pressure loss over the test period. The expressions are

$$P_{allowable} = P_{He} \times \exp(-W_{He} / M_{He} \times t_{period}) \qquad \textit{Equation 9}$$

and

$$\Delta P_{allowable} = P_{He} \times (1 - \exp(-W_{He} / M_{He} \times t_{period})) \qquad \textit{Equation 10}$$

where t_{period} is the period of the test.

Use of the above equations can be best illustrated by providing an example for a typical passenger vehicle with a 100 liter (L) volume LHSS . Per groundrule, the basic safety parameters are established to be the same as that for the Compressed Hydrogen Storage System (CHSS). Specifically, the period of the leak test is 60 minutes and the average H_2 leakage must be equivalent to 118 NL/minute. Using these parameters for the example yields the following:

Post-crash test period (t_{period}) = 60 minutes
Allowable Liquid H_2 Leakage (W_l) = 10.7 g/min = 118 NL/min of gas after flashing
Maximum Allowable Working Pressure (MAWP) = 6 atm (gauge) = 7 atm (absolute)
Selected Helium Test Pressure (P_{He}) below Pressure Regulator Setpoints = 5.9 atm (absolute)
Ratio of specific heat (k) for helium = 1.66
C for helium = 0.725 from *Equation 3*
Helium Density at Initial Test Pressure = 0.991 g/L
Density of Liquified Hydrogen = 71.0 g/L
Liquid Hydrogen Leakage Pressure Drop (ΔP_l) = 5.9 atm – 1 atm = 4.9 atm
Mass Ratio of Helium to Liquid H_2 Leakage (W_{He} / W_l) = 0.0668
Allowable Initial Helium Leakage (W_{He}) = 7.15 g/min = 4.01 NL/min
Initial Mass of Helium in the LHSS for the test (M_{He}) = 99.1 g from *Equation 6*
Allowable Reduction in Helium Pressure ($\Delta P_{allowable}$) = 1.97 atm from *Equation 10*

The above example illustrates how the equations can be used to determine the reduction in helium pressure over the 60 minutes test period for the leak test. While the methodology results in objective result from a commonly-used type of test, it should be noted that the criterium is very conservative in that the methodology assumes liquid leakage rather than the more likely gaseous leakage from the pipig and valves downstream of the LHSS container . For example, the ratio of hydrogen gas leakage can be determined using *Equation 2* and the resulting ratio of allowable helium gas leakage to hydrogen gas leakage is a factor of 6 higher than that calculated assuming liquefied hydrogen leaks, thus illustrating the conservatism. None the less, the use of this test method is straight-forward, objective, and practical to conduct in a crashed vehicle and therefore adopted for the purpose of regulatory requirements.

During the crash test, the LHSS is filled with either liquefied hydrogen (LH2) to the maximum quantity or liquefied nitrogen (LN2) to at least 10% of the maximum liquefied hydrogen volume in the LHSS, depending which fluid is planned for the crash test. The LN2 volume is selected to ensure an appropriate simulation of fuel weight for the crash test, we desire about 7% fill for the crash test. Slightly more liquefied nitrogen is added to accommodate system cooling and venting prior to the test.

A.6.1.2 Rationale for B.6.1.2 Test Procedure for Post-Crash Concentration Test in Enclosed Spaces

This post-crash test is organized as follows:

B.6.1.2.1 Post-crash enclosed-space test for compressed hydrogen storage systems
B.6.1.2.2 Post-crash enclosed-space test for liquid hydrogen storage systems

A.6.1.2.1 Rationale for B.6.1.2.1 Test Procedure for Post-Crash Concentration Measurement for Vehicles with Compressed Hydrogen Storage Systems (CHSSs)

The test may be conducted directly by measuring hydrogen or the corresponding depression in oxygen content, if the CHSS contains hydrogen for the crash test. Sensors are to be located at significant locations (as defined in B.6.1.2.1) in the passenger, luggage, and cargo compartments.Since the test is conducted in parallel with the post-crash leak test of the CHSS and therefore will extend for at least 60 minutes, there is no need to provide margin on the criteria to manage dilution zones as there is sufficient time for the hydrogen to diffuse throughout the compartment.

In the case where the vehicle is not crashed with hydrogen and a leak test is conducted with compressed helium (rather than compressed hydrogen, it is necessary to define a criteria for the helium content that is equivalent to 4% hydrogen by volume. Recognizing that the content of hydrogen or helium in the compartment (by volume) is proportional to the volumtric flow of the respective releases, it is possible to determine the allowable helium content by volume, X_{He}, from the equation developed in A.6.1.1.1 by multiplying the hydrogen concentration criteria by the 0.75. The criteria for helium concentration is therefore as follows:X_{He} = 4% H2 by volume x 0.75 = 3.0% by volume.

The criteria for helium concentration is therefore 3% by volume in the passenger, luggage, and cargo compartments if the crash test of a vehicle with a CHSS is conducted with compressed helium instead of compressed hydrogen.

A.6.1.2.2 Rationale for B.6.1.2.2 Test Procedure for Post-Crash Concentration Measurement for Vehicles with Liquefied Hydrogen Storage Systems (LHSSs)

As with vehicles with CHSSs, direct measurement of hydrogen vehicles or the corresponding depression in oxygen content, is possible if the vehicle contains hydrogen in Liquefied Hydrogen Storage Systems (LHSSs) for the crash test.

In the case where liquefied nitrogen is used for the crash, the concentration of helium in the passenger, luggage, and cargo compartments may be measured during the helium leak test which is conducted after the crash. As with the CHSS, it is possible to establish a helium concentration criteria which is equivalent to 4% hydrogen concentration by volume, but the relationship needs to adjust for the difference in temperature of the gas between the operating LHSS and the temperature during the helium leak test in addition to accounting for differences in physical properties. The liquefied hydrogen is stored (and will leak) at cryogenic storage temperatures (-253C or 20K), but the system is approximately room temperature (20C or 293K) for the leak test. In this case, the equations given in A.6.1.1.1 may used to express the ratio of helium and hydrogen mass flows is as

$$W_{He}/W_{H2} = C_{He}/C_{H2} \times (M_{He} / M_{H2})^{1/2} \times (T_{H2} / T_{He})^{1/2}$$

and the ratio of helium and hydrogen volumetric flows as

$$V_{He} / V_{H2} = C_{He} / C_{H2} \times (M_{H2} / M_{He})^{1/2} \times (T_{He} / T_{H2})^{1/2}$$

where terms are as defined in A.5.2.1.1. Applying the volumetric flow ratio as defined above to account for a system that operates at cryogenic storage conditions but is leak tested at room temperature to the requirement that there be no greater than 4% by volume of hydrogen in the actual vehicle, yields a value of approximately 0.8% by volume of helium as the allowable value for the LHSS post-crash test based on the leakage of gas from the LHSS.

A.7. RATIONALE FOR ANNEX B.7 TYPE APPROVAL REQUIREMENTS FOR COMPRESSED AND LIQUEFIED HYDROGEN SYSTEMS

The Qualification Performance Requirements (Section B.5) provide qualification requirements for on-road service for compressed and liquefied hydrogen fuel systems. Additional requirements in Annex B.7 are applicable for Contracting Parties with Type Approval systems that address Conformity of Production with units qualified for on-road service through performance testing. The goal of harmonization of requirements as embodied in the United Nations Global Technical Regulations provides the opportunity to develop vehicles that can be deployed throughout Contracting Parties to achieve uniformity of compliance; therefore, Type Approval requirements beyond those specified in Annex B.7 are not expected.

A.7.1 Rationale for B.7.1 Type Approval Requirements for Compressed Hydrogen Storage. Type Approval requirements provide assurance that manufactured systems are consistent with units formally tested and qualified for on-road service in B.5.1, and that material durability is verified. The following requirements are for qualification of vehicles for on-road service in Contracting Parties having Type Approval systems.

- Material test requirements (B.7.1.1)
- Verification tests for consistency of design qualification batch (B.7.1.2)
- Verification tests for conformity of production (B.7.1.3)
- Qualification tests for storage system hydrogen-flow closures (B.7.1.4)

A.7.1.1 Rationale for B.7.1.1 Material Test Requirements. Compliance with Test Requirements of B.6.2.1 ensure that manufacturers consistently use materials that are appropriately qualified for hydrogen service and that meet design specifications of the manufacturer.

- B.6.2.1.1 tests are specified for type approval verification of conformity of production; for example, manufacturers of storage systems must maintain information relevant to the system design that includes tensile properties and softening temperature (greater than100C) of plastic liner material, glass transition temperature, resin shear strength, and coating adhesion and flexibility.
- B.6.2.1.2 stipulates requirements for resistance to hydrogen embrittlement. The requirement specifies materials recognized as having demonstrated successful historical on-road usage with hydrogen. It is expected that individual Contracting Parties may develop material test requirements to permit use of additional materials within their individual jurisdictions.
- B.6.2.1.3 provides the performance test requirement for stress rupture resistance. Qualification of systems for long-term parking under full fill conditions (25 years at 100%NWP) is provided by B.5.1.2.5 which requires 1000hr at 125%NWP – the equivalence of these requirements is based on the relationship between time-to-failure and applied stress that was established (Aerospace Corp Report No. ATR-92(2743)-1 (1991) and references therein) for the current worst-case vessel structural material (glass fiber reinforced composite). The B.6.2.1.3 performance test verifies that the vessel is constructed from materials that have a relationship between time-to-failure and applied stress that is better than the worst-case relationship for glass fiber reinforced composite that was used as the basis for B.5.1.2.5 -- thereby verifying the applicability of the qualification test B.5.1.2.5. That worse-case relationship is that a x10^2 increase in time-to-failure is associated with a 18% decrease in the sustained pressure. The B.6.2.1.3 performance test verifies that a x10^2 increase in time-to-failure is linked to no more than a 9% decrease in pressure – this provides a margin for performance beyond the glass-fiber composite limit. It also accommodates an additional parking target of 115% NWP for 10 years, which provides for commercial vehicles with highly thermally insulated containment vessels that are used in very warm climates and fully fuel from empty at the end of each work day and immediately park for over 12 hours.

  Because the B.6.2.1.3 qualification test is unusually burdensome (it requires over a year to complete), systems for which public experimental data are available for the vessels or vessel structural material and for which on-road service experience is extensive may qualify by alternative criteria. The exception from B.5.2.1.3 requirements for carbon-fiber reinforced composite vessels is based on extensive experimental material data (e.g. Aerospace Corp Report No. ATR-92(2743)-1 (1991) and references therein) and experience with on-road vehicle service. The conditional exception from B.5.2.1.3 requirements for glass-fiber reinforced composite vessels is based on extensive experimental material data (e.g. Aerospace Corp Report No. ATR-92(2743)-1 (1991) and references therein) and experience with extensive on-road vehicle service –in the case of glass-fiber composites, the material data supports the expectation that if the vessel material is capable of sustaining 330%NWP for 30 seconds, then it could sustain 180%NWP for over 25 years, which would ensure capability to meet the 180%NWP end-of-life requirement. Therefore, the conditional exception from B.5.2.1.3 testing for glass-fiber composite vessels is that the vessels demonstrate a proof pressure of 330% NWP. Comparably extensive experimental data (relationship between time-to-failure and stress), and comparably extensive experience with on-road service are not available for other vessel materials; hence those vessels are required to undergo the B.6.2.3.1 test.

A.7.1.2 Rationale for B.7.1.3 Verification Tests for Conformity of Production. Design qualification testing is only meaningful if the tested unit(s) is representative of expected performance of production units. Manufacturers are expected to ensure that all production units meet the requirements of performance verification testing in B.5.1.2. Establishing key metrics of units tested for performance is required for documentation that the quality of manufacturing units is at least comparable to that of batch-qualification units. The requirement that the burst pressure of production units be controlled to greater than 90% BP_0 and greater than or equal to 200% NWP provides assurance that the full range of production containers are accommodated in performance requirements.

A.7.1.3 Rationale for B.7.1.4 Qualification Tests for Storage-System Hydrogen-flow Closures. The reliability and durability of hydrogen-flow closures is essential for the integrity of the full storage system. The closures are partially qualified by their function in the system-level performance tests (B.5.1). In addition, these closures are qualified individually not only to assure exceptional reliability for these moving parts, but also to enable equivalent components to be exchanged in a storage system without re-qualifying the entire storage system. Closures that isolate high pressure hydrogen from the remainder of the fuel system and the environment include:

- thermally-activated pressure relief device (TPRD, a TPRD opens and remains open when the system is exposed to fire.)
- check valve (A check valve prevents reverse flow in the vehicle fill line, e.g., a non-return valve.) Equivalent to a non-return valve.
- shut-off valve (A shut-off valve between the storage container and the vehicle fuel system defaults to the closed position when unpowered.)

Test procedures for qualification of hydrogen-flow closures within the hydrogen storage system were developed by OICA as outgrowths of discussions within CSA workgroups for HPRD1:2009 and HGV3.1 (as yet unpublished), and reports to those CSA workgroups testing sponsored by US-DOE and performed at Powertech Laboratories to verify closure test procedures under discussion within CSA.

A.7.1.3.1 Rationale for TPRD Qualification Requirements. The qualification requirements verify that the design shall be such that, once activated, the device will fully vent the contents of the fuel container even at the end of the service life when the device has been exposed to fueling/de-fueling pressure and temperature changes and environmental exposures. The adequacy of flow rate for a given application is verified by the hydrogen storage system fire test requirements (B.5.1.4).

A.7.1.3.2 Rationale for Check Valve Qualification Requirements. These requirements are not intended to prevent the design and construction of components (e.g. components having multiple functions) that are not specifically prescribed in this standard, provided that such alternatives have been considered in testing the components. In considering alternative designs or construction, the materials or methods used shall be evaluated by the testing facility to ensure equivalent performance and reasonable concepts of safety to that prescribed by this standard. In that case, the number of samples and order of applicable tests shall be mutually agreed upon by the manufacturer and the testing agency. Unless otherwise specified, all tests shall be conducted using hydrogen gas that complies with SAE J2719 (Information Report on the Development of a Hydrogen Quality Guideline for Fuel Cell Vehicles), or ISO 14687-2 (Hydrogen Fuel-Product Specification). The total number of operational cycles shall be 11,000 (fueling cycles) for the check valve and 50,000 (duty cycles) for the automatic shut-off valve.

Fuel flow shut-off by an automatic shut-off valve mounted on a compressed hydrogen storage vessel shall be fail safe. The term “fail safe” shall refer to a device’s ability to revert to a safe mode or a safe complete shutdown for all reasonable failure modes.

The electrical tests for the automatic shut-off valve mounted on the compressed hydrogen storage vessels (B.8.2.7) provide assurance of performance with: (1) over temperature caused by an overvoltage condition, and (2) potential failure of the insulation between the component’s power conductor and the component casing. The purpose of the Pre-Cooled Hydrogen Exposure Test (B.8.2.10) is to verify that all components in the flow path from the receptacle to the container that are exposed to precooled hydrogen during fuelling can continue to operate safely.

A.8. EXISTING REGULATIONS, DIRECTIVES, AND INTERNATIONAL STANDARDS

A.8.1 VEHICLE FUEL SYSTEM INTEGRITY

A.8.1.1 National regulations and directives.

- European Union -- Regulation 406/2010 implementing EC Regulation 79/2009
- Japan -- Safety Regulation Article 17 and Attachment 17 – Technical Standard for Fuel Leakage in Collision
- Japan -- Attachment 100 – Technical Standard For Fuel Systems Of Motor Vehicle Fueled By Compressed Hydrogen Gas
- Canada -- Motor Vehicle Safety Standard (CMVSS) 301.1 – Fuel System Integrity
- Canada -- Motor Vehicle Safety Standard (CMVSS) 301.2 – CNG Vehicles
- Korea -- Motor Vehicle Safety Standard, Article 91 – Fuel System Integrity
- United States -- Federal Motor Vehicle Safety Standard (FMVSS) No. 301 - Fuel System Integrity.
- United States -- FMVSS No. 303 – CNG Vehicles

A.8.1.2 International standards.

- ISO 17268 -- Compressed hydrogen surface vehicle refuelling connection devices
- ISO 23273-1 -- Fuel cell road vehicles — Safety specifications — Part 1: Vehicle functional safety

- ISO 23273-2 -- Fuel cell road vehicles — Safety specifications — Part 2: Protection against hydrogen hazards for vehicles fuelled with compressed hydrogen
- ISO 14687-2 -- Hydrogen Fuel — Product Specification — Part 2: Proton exchange membrane (PEM) fuel cell applications for road vehicles
- SAE J2578 -- General Fuel Cell Vehicle Safety
- SAE J2600 – Compressed Hydrogen Surface Vehicle Fueling Connection Devices
- SAE J2601 – Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles
- SAE J2799 – Hydrogen Quality Guideline for Fuel Cell Vehicles

A.8.2 STORAGE-SYSTEM

A.8.2.1 National regulations and directives:

- China -- ### Regulation on Safety Supervision for Special Equipment
- China -- ### Regulation on Safety Supervision for Gas Cylinder
- Japan -- JARI S001(2004) Technical Standard for Containers of Compressed Hydrogen Vehicle Fuel Devices
- Japan -- JARI S002(2004) Technical Standard for Components of Compressed Hydrogen Vehicle Fuel Devices
- Japan -- KHK 0128(2010) Technical Standard for Compressed Hydrogen Vehicle Fuel Containers with Maximum Filling Pressure up to 70MPa
- Korea -- ### High Pressure Gas Safety Control Law
- United States -- FMVSS 304 - Compressed Natural Gas fuel Container Integrity
- European Union -- Regulation 406/2010 implementing EC Regulation 79/2009

A.8.2.2 International standards:

- CSA B51.2 -- Hydrogen and CNG Vessels
- CSA NGV2-2000 – Basic Requirements for Compressed Natural Gas Vehicle (NGV) Fuel Containers
- CSA HPRD-1-2009 – Pressure Relief Devices For Compressed Hydrogen Vehicle Fuel Containers
- CSA HGV 3.1-2011 – Fuel System Component for Hydrogen Gas Power Vehicles (Draft)
- ISO 13985:2006 -- Liquid Hydrogen – Land Vehicle Fuel Tanks
- ISO 15869:2009 -- Gaseous Hydrogen and Hydrogen Blends – Land Vehicle Fuel Tanks (Technical Specification)
- SAE J2579 -- Fuel Systems in Fuel Cell and Other Hydrogen Vehicles

A.8.3 ELECTRIC SAFETY

A.8.3.1 National regulations:

- Canada -- CMVSS 305—Electric Powered Vehicles: Electrolyte Spillage And Electrical Shock Protection

- ECE -- Regulation 100 - Uniform Provisions Concerning The Approval Of Battery Electric Vehicles With Regard To Specific Requirements for The Construction AND Functional Safety
- Japan -- Attachment 101 – Technical Standard for Protection of Occupants against High Voltage in Fuel Cell Vehicles
- Japan -- Attachment 110 – Technical Standard for Protection of Occupants against High Voltage in Electric Vehicles and Hybrid Electric Vehicles
- Japan -- Attachment 111 – Technical Standard for Protection of Occupants against High Voltage after Collision in Electric Vehicles and Hybrid Electric Vehicles
- Great Britain -- T 24548-2009 Fuel cell electric vehicles - terminology
- Great Britain -- T 24549-2009 Fuel cell electric vehicles - safety requirements
- Great Britain -- T 24554-2009 Fuel cell engine - performance - test methods
- 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
- ????? -- QC/T 816-2209 Hydrogen supplying and refueling vehicles -specifications
- United States -- FMVSS 305 - Electric-Powered Vehicles: Electrolyte Spillage and Electrical Shock Protection

A.8.3.2 International Industry standards:

- ISO 23273-3 -- Fuel cell road vehicles — Safety specifications — Part 3: Protection of persons against electric shock
- SAE J1766 -- Electric and Hybrid Electric Vehicle Battery Systems Crash Integrity Testing
- SAE J2578 -- General Fuel Cell Vehicle Safety

A.9. DISCUSSION OF KEY ISSUES

⇒⇒Delete this section?

A.10. BENEFITS AND COSTS

⇒⇒ Delete this section?

PART B. TEXT OF REGULATION

B.1. PURPOSE

B.1 This regulation specifies safety-related performance requirements for hydrogen-fueled vehicles. The purpose of this regulation is to minimize human harm that may occur as a result of fire, burst or explosion related to the vehicle fuel system and/or from electric shock caused by the vehicle's high voltage system.

B.2. SCOPE

B.2 This regulation applies to all hydrogen fueled vehicles of Category 1-1 and 1-2, with a gross vehicle mass (GVM) of 4,536 kilograms or less. Contracting Parties under the Type Approval system shall adopt Annex B.7.

B.3. DEFINITIONS

For the purpose of this regulation, the following definitions shall apply:

Hydrogen-fueled vehicle means any motor vehicle that uses compressed gaseous or liquefied hydrogen as fuel to propel the vehicle including fuel cell and internal combustion engine vehicles.

B.3.1 Vehicle fuel system means an assembly of components used to store or supply hydrogen fuel to a fuel cell (FC) or internal combustion engine (ICE).

B.3.2 Hydrogen storage system means pressurized container(s), pressure Relief devices (PRDs), shut off device(s), and all components, fittings and fuel lines that isolate the stored hydrogen from the remainder of the fuel system and the environment.

B.3.3 Pressure relief device (PRD) means a device that, when activated under specified performance conditions, is used to release hydrogen from a pressurized system and thereby prevent failure of the system.

B.3.4 Burst-disc means a pressure activated PRD that opens once activated and cannot re-close.

B.3.5 Thermally-activated pressure relief device (TPRD) means a thermally activated PRD that opens once activated and cannot re-close.

B.3.6 Pressure relief valve means a pressure relief device that opens at a preset pressure level and can re-close.

B.3.7 Check valve means a non-return valve that prevents reverse flow in the vehicle fuel line.

B.3.8 Shut-off valve means a valve between the storage container and the vehicle fuel system that can be automatically activated and defaults to the closed position when unpowered.

B.3.9 Single failure means a failure caused by a single event, including any consequential failures resulting from this failure.

B.3.10 Lower Flammability limit (LFL) means the lowest concentration of fuel at which a gaseous fuel mixture is flammable at normal temperature and pressure. The lower flammability limit for hydrogen gas in air is 4% by volume (A.5.3.1.6).

B.3.11 Rupture and Burst both mean come apart suddenly and violently, break open or fly into pieces due to the force of internal pressure.

B.3.12 The exhaust's point of discharge means the geometric center of the area where fuel cell purged gas is discharged from the vehicle.

B.3.13 High voltage means the classification of an electric component or circuit, if its maximum working voltage is greater than 60 V and less than or equal to 1500 V of direct current (DC) or greater than 30 V and less than or equal to 1000 V of alternating current (AC).

B.3.14 Enclosed or semi-enclosed spaces means the volumes within the vehicle (or the vehicle outline across openings) that are external to the hydrogen system and its housings (if any) where hydrogen may accumulate (and thereby pose a hazard) such as the passenger compartment, luggage compartment, cargo compartment, or space under the hood.

B.3.15 Nominal Working Pressure (NWP) means the gauge pressure that characterizes typical operation of a system. For compressed hydrogen gas containers, NWP is the settled pressure of compressed gas in fully fueled container, container or system at a uniform temperature of 15^{o}C.

B.3.16 Maximum Allowable Working Pressure (MAWP) means the highest gauge pressure to which a pressure container, container, or system is permitted to operate under normal operating conditions.

B.3.17 Maximum Fueling Pressure (MFP) means for compressed systems, the maximum fueling pressure is 125% of the Nominal Working Pressure.

B.3.18 Type Approval means the confirmation by means of certification through a recognised body that prototype or pre-production samples of a specific vehicle, vehicle system or vehicle system component meet the relevant specified performance standards, and that the final production versions also comply, as long as conformity of production is confirmed.

B.3.19 Service Life means the maximum time period for which service (usage) is qualified and/or authorized.

B.3.20 Date of Removal from Service means the calendar date (month and year) specified for removal from service.

B.3.21 Active driving possible mode means the vehicle mode when application of pressure to the accelerator pedal (or activation of an equivalent control) or release of the brake system will cause the electric power train to move the vehicle.

B.3.22 Automatic disconnect means a device that when triggered, conductively separates the electrical energy sources from the rest of the high voltage circuit of the electrical power train.

B.3.23 Conductive connection means the connection using contactors to an external power supply when the rechargeable energy storage system (RESS) is charged.

B.3.24 Coupling system for charging the rechargeable energy storage system (RESS) means the electrical circuit used for charging the RESS from an external electric power supply including the vehicle inlet.

B.3.25 Direct contact means the contact of persons with high voltage live parts.

B.3.26 Electrical chassis means a set made of conductive parts electrically linked together, whose electrical potential is taken as reference.

B.3.27 Electrical circuit means an assembly of connected high voltage live parts which is designed to be electrically energized in normal operation.

B.3.28 Electrical isolation means the electrical resistance between the vehicle high voltage bus source and any vehicle conductive structure.

B.3.29 Electrical Protection Barrier means the part providing protection against direct contact to the live parts from any direction of access.

B.3.30 Electric energy conversion system means a system (e.g. fuel cell) that generates and provides electrical energy for vehicle propulsion.

B.3.31 Electric power train means the electrical circuit which may includes the traction motor(s), and may also include the RESS, the electrical energy conversion system, the electronic converters, the traction motors, the associated wiring harness and connectors, and the coupling system for charging the RESS

B.3.32 Electronic converter means a device capable of controlling and/or converting electric power for electrical power for propulsion.

B.3.33 Enclosure means the part enclosing the internal units and providing protection against any direct contact.

B.3.34 Exposed conductive part means the conductive part which can be touched under the provisions of the protection degree IPXXB, and which becomes electrically energized under isolation failure conditions.

B.3.35 External electric power supply means an alternating current (AC) or direct current (DC) electric power supply outside of the vehicle.

B.3.36 High Voltage means the classification of an electric component or circuit, if it's maximum working voltage is > 60 V and ≤ 1500 V direct current (DC) or > 30 V and ≤ 1000 V alternating current (AC) root mean square (rms).

B.3.37 High Voltage Bus means the electrical circuit, including the coupling system for charging the RESS that operates on high voltage.

B.3.38 Indirect contact means the contact of persons with exposed conductive parts.

B.3.39 Live parts means the conductive part(s) intended to be electrically energized in normal use.

B.3.40 Luggage compartment means the space in the vehicle for luggage accommodation, bounded by the roof, hood, floor, side walls, as well as by the electrical protection barrier and enclosure provided for protecting the power train from direct contact with live parts, being separated from the passenger compartment by the front bulkhead or the rear bulk head.

B.3.41 On-board isolation resistance monitoring system means the device which monitors the isolation resistance between the high voltage buses and the electrical chassis.

B.3.42 Open type traction battery means a type of battery requiring liquid and generating hydrogen gas released to the atmosphere.

B.3.43 Passenger compartment for electric safety assessment means the space for occupant accommodation, bounded by the roof, floor, side walls, doors, outside glazing, front bulkhead and rear bulkhead, or rear gate, as well as by the electrical protection electrical protection barriers and enclosures provided for protecting the power train from direct contact with live parts.

B.3.44 Protection IPXXB means protection from contact with high voltage live parts provided by either an electrical protection barrier or an enclosure and tested using a Jointed Test Finger (IPXXB) as described in B.6.4.3.

B.3.45 Protection IPXXD means protection from contact with high voltage live parts provided by either an electrical protection barrier or an enclosure and tested using a Test Wire (IPXXD) as described in B.6.4.3.

B.3.46 Rechargeable energy storage system (RESS) means the rechargeable energy storage system which provides electric energy for electrical propulsion.

B.3.47 Service disconnect means the device for deactivation of the electrical circuit when conducting checks and services of the RESS, fuel cell stack, etc.

B.3.48 Solid insulator means the insulating coating of wiring harnesses provided in order to cover and prevent the high voltage live parts from any direct contact. This includes covers for insulating the high voltage live parts of connectors and varnish or paint for the purpose of insulation.

B.3.49 Working voltage means the highest value of an electrical circuit voltage root mean square (rms), specified by the manufacturer or determined by measurement, which may occur between any conductive parts in open circuit conditions or under normal operating condition. If the electrical circuit is divided by galvanic isolation, the working voltage is defined for each divided circuit, respectively.

B.4. APPLICABILITY OF REQUIREMENTS

B.4.1 The requirements of sections B.5.1 and B.5.3 (using test procedures given in B.6) apply to all compressed hydrogen fueled vehicles.

B.4.2 The requirements of sections B.5.2 and B.5.3 (using test procedures given in B.6) apply to all liquid hydrogen fueled vehicles.

B.4.3 Each contracting party under the UNECE 1998 Agreement will maintain its existing national crash tests and use the limit values of section B.5.3.2 for compliance.

B.4.4 The requirements of section B.5.4 apply to all hydrogen-fueled vehicles using high voltage.

B.4.4 The requirements in Annex B.7 are applicable for Contracting Parties with Type Approval systems.

B.5. PERFORMANCE REQUIREMENTS

B.5.1 COMPRESSED HYDROGEN STORAGE SYSTEM

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 primary closures of openings into the high pressure storage container(s). For the illustration in Figure B.5.1.1, the primary closures include the thermally-activated pressure relief device (TPRD), the check valve that prevents reverse flow to the fill line, the shut-off valve that can close to prevent flow to the fuel cell or ICE engine, and all components, fittings and fuel lines that isolate the high pressure storage system from the remainder of the fuel system and environment.

Any shut-off valve(s), and TPRD(s) that form the primary closure of flow from the storage container shall be mounted directly on or within each container As well as at least one component with a check valve function.

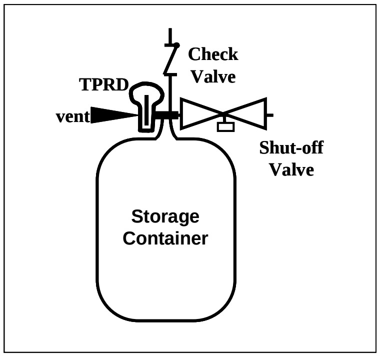


Figure B.5.1.1 Typical Compressed Hydrogen Storage System

All new hydrogen storage systems produced for on-road vehicle service shall have a NWP of 70 MPa or less and a service life of 15 years or less, and be capable of satisfying the requirements of B.5.1.

The hydrogen storage system shall be qualified to the performance test requirements specified in this Section B.5.1. The qualification requirements for on-road service are:

B.5.1.1 Verification Tests for Baseline Metrics
B.5.1.2 Verification Test for Performance Durability
B.5.1.3 Verification Test for Expected On-Road Performance
B.5.1.4 Verification Test for Service Terminating Performance

The test elements within these performance requirements are summarized in Table B.5.1. Test procedures are specified in Section B.6.

Table B.5.1
Overview of Performance Qualification Test Requirements

B.5.1.1 Verification Tests for Baseline Metrics B.5.1.1.1 Baseline Initial Burst Pressure B.5.1.1.2 Baseline Initial Pressure Cycle Life
B.5.1.2 Verification Test for Performance Durability (sequential hydraulic tests) B.5.1.2.1 Proof Pressure Test B.5.1.2.2 Drop (Impact) Test B.5.1.2.3 Surface damage B.5.1.2.4 Chemical Exposure and Ambient Temperature Pressure Cycling Tests B.5.1.2.5 High Temperature Static Pressure Test

B.5.1.1 Verification Tests for Baseline Performance Metrics

B.5.1.1.1 Baseline Initial Burst Pressure.

Three (3) new containers randomly selected from the design qualification batch of at least 10 containers, shall be hydraulically pressurized until burst (B.6.2.2.1 test procedure). The manufacturer shall supply documentation (measurements and statistical analyses) that establishes the midpoint burst pressure of new storage containers, BP_O.

All containers tested must have a burst pressure within $\pm$10% of BP_O and greater than or equal to a minimum BP_{min} of 200% NWP.

B.5.1.1.2 Baseline Initial Pressure Cycle Life.

Three (3) randomly selected new container shall be hydraulically pressure cycled to 125% NWP without rupture for 22,000 cycles or until leak occurs (B.6.2.2.2 test procedure). Leakage shall not occur within #Cycles, where #Cycles is set individually by each Contracting Party within the constraint that for the 15 years service life, the required #Cycles cannot be greater than 11,000, and it could be set at a lower number but not lower than 5,500 cycles.

B.5.1.2 Verification Tests for Performance Durability (Hydraulic sequential tests)

A hydrogen storage container must not leak during the following sequence of tests, which are applied in series to a single system and which are illustrated in Figure B.5.1.2. 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 B.6.2.3.

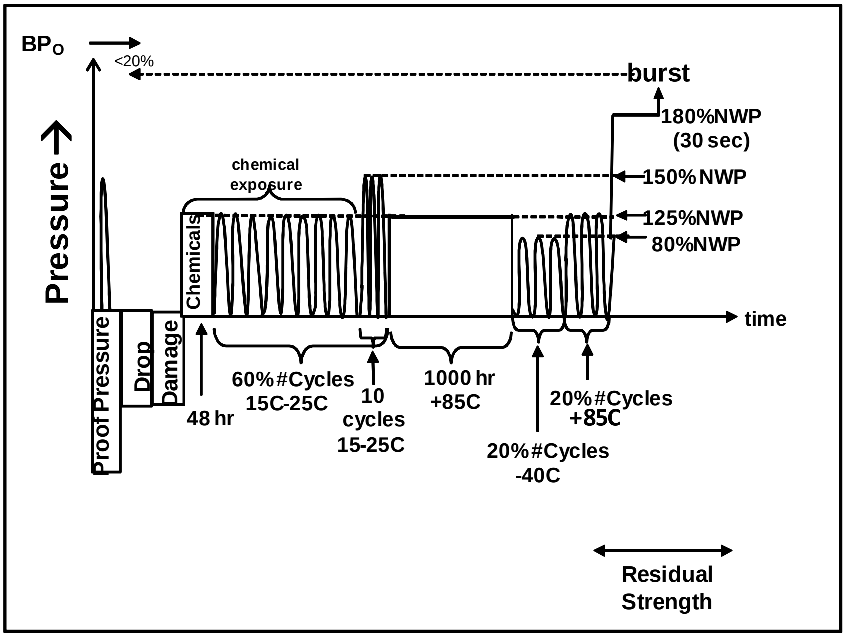


Figure B. 5.1.2 Verification Test for Performance Durability (hydraulic)

B.5.1.2.1 Proof Pressure Test. A storage container will be pressurized to 150%NWP (B.6.2.3.1 test procedure). A storage container that has undergone a proof pressure test in manufacture is exempt from this test.

B.5.1.2.2 Drop (Impact) Test. The storage container will be dropped at several impact angles (B.6.2.3.2 test procedure).

B.5.1.2.3 Surface Damage Test: The storage container will be subjected to surface damage (B.6.2.3.3 test procedure).

B.5.1.2.4 Chemical Exposure and Ambient-Temperature Pressure Cycling Test. The storage container will be exposed to chemicals found in the on-road environment and pressure cycled to 125% NWP at 20 ($\pm 5^{o}$C) for 60% #Cycles pressure cycles (B.6.2.3.4 test procedure). Chemical exposure will be discontinued before the last 10 cycles, which are conducted to 150% NWP.

B.5.1.2.5 High Temperature Static Pressure Test. The storage container will be pressurized to 125%NWP at 85^{o}C for 1000 hr (B.6.2.3.5 test procedure).

B.5.1.2.6 Extreme Temperature Pressure Cycling. The storage system will be pressure cycled at -40C to 80%NWP for 20% #Cycles cycles and at +85°C to 125%NWP for 20% #Cycles (B.6.2.3.2 test procedure).

B.5.1.2.7 Hydraulic Residual Pressure Test. The storage container will be pressurized to 180%NWP and held 30 seconds without burst (test procedure B.6.2.3.1).

B.5.1.2.8 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 initial burst pressure determined in B.5.1.1.1 (B.6.2.2.1 test procedure).

B.5.1.3 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 B.5.1.3. Specifics of applicable test procedures for the hydrogen storage system are provided in Section 6.

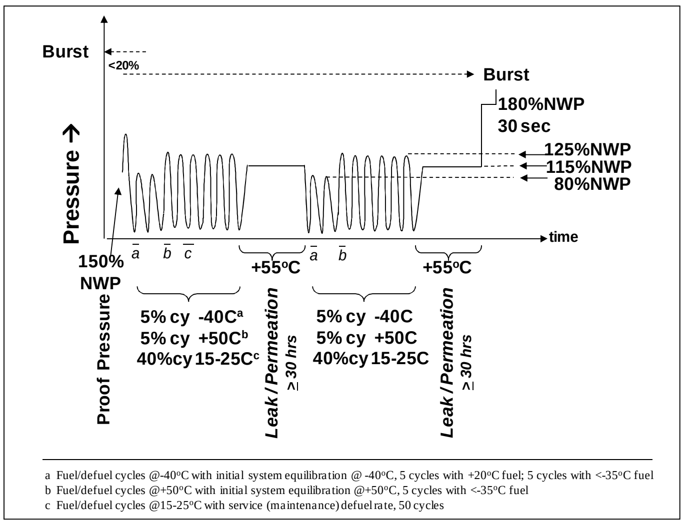


Figure B.5.1.3 Verification Test for Expected On-Road Performance (pneumatic/hydraulic)

B.5.1.3.1 Proof Pressure Test: A system will be pressurized to 150%NWP (B.6.2.3.1 test procedure).

B.5.1.3.2 Ambient and Extreme Temperature Gas Pressure Cycling Test. The system will be pressure cycled using hydrogen gas for 500 cycles (B.6.2.4.1 test procedure).

- The pressure cycles will be divided into two groups: Half of the cycles (250) will be performed before exposure to static pressure (B.5.1.3.3) and the remaining half of the cycles (250) will be performed after the initial exposure to static pressure (B.5.1.3.3) as illustrated in Figure B.5.1.3.

- In each group of pressure cycling, 25 cycles will be performed to 125% NWP at +50°C and 95% relative humidity, then 25 cycles to 80% NWP at -40°C, and the remaining 200 cycles to 125% NWP at 20 (±5)°C.
- The hydrogen gas fuel temperature will be -40 (±5)°C.
- During the first group of 250 pressure cycles, five cycles will be performed after temperature equilibration of the system at 50°C and 95% relative humidity; five cycles will be performed after equilibration at -40°C; and five cycles will be performed with fuel having a temperature of +20°C after equilibration at -40°C.
- Fifty pressure cycles will be performed using a defueling rate greater than or equal to the maintenance defueling rate.

B.5.1.3.3 Extreme Temperature Static Pressure Leak/Permeation Test. The system will be held at 115%NWP and 55°C with hydrogen gas until steady-state permeation or 30 hours, whichever is longer (B.6.2.4.2 test procedure).

- The test will be performed after each group of 250 pneumatic pressure cycles in B.5.1.3. 2.
- The maximum allowable hydrogen discharge from the compressed hydrogen storage system is R*150ml/min where $R = (V_{width}+1)*(V_{height}+0.5)*(V_{length}+1)/30.4m^3$ and V_{width}, V_{height} and V_{length} are the vehicle width, height and length respectively in meters.
- Alternatively, the maximum allowable hydrogen discharge from the compressed hydrogen storage system with a total water capacity of less than 330L is 46mL/h/L water capacity of the storage system.
- 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) (B.6.2.4.3 test procedure).

B.5.1.3.4 Residual Proof Pressure Test (hydraulic). The storage container will be pressurized to 180%NWP and held 4 minutes without burst (B.6.2.3.1 test procedure).

B.5.1.3.5 Residual Strength Burst Test (hydraulic). The storage container will undergo a hydraulic burst to verify that the burst pressure is within 20% of the baseline burst pressure determined in B.5.1.1.1 (B.6.2.2.1 test procedure).

B.5.1.4 Verification Test for Service Terminating Performance in Fire

⇒⇒Suggestion: delete the following PART B text in favor of the explicit text added in PART A A.4.3 (1)

~~This section describes the fire test with compressed hydrogen as the test gas. However, contracting party under the 1998 Agreement may choose to use compressed air as an alternative test gas for certification of the container for use in its country or region. Containers tested with hydrogen gas shall be accepted by all contracting parties.~~

A hydrogen storage system will be pressurized to NWP and exposed to fire (B.6.2.5.1 test procedure). A temperature-activated pressure relief device will release the contained gases in a controlled manner without rupture.

B.5.1.5 Labeling.

A label shall be permanently affixed on each container with at least the following information: Name of the Manufacturer, Serial Number, Date of Manufacture, NWP, Type of Fuel, and Date of Removal from Service. Any label affixed to the container in compliance with this section shall remain in place and be legible for duration of the manufacturer's recommended service life of the container. Contracting parties may specify additional labeling requirements.

B.5.2 LIQUEFIED HYDROGEN STORAGE SYSTEM

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

The hydrogen storage system will be qualified to the performance test requirements specified in this Section. All liquefied hydrogen storage systems produced for on-road vehicle service must be capable of satisfying requirements of B.5.2.

The manufacturer has to provide a confirmation of hydrogen material compatibility for the inner tank and all components in contact with hydrogen. Furthermore, the manufacturer is obliged to specify a maximum allowable working pressure (MAWP) for the inner container. In order to prove proper design and expected on-road performance of the storage the following tests have to be accomplished:

- Proof pressure test
- Baseline Initial Burst Pressure (hydraulic)
- Boil-off test
- Leak test
- Vacuum loss test
- Bonfire test

The test elements within these performance requirements are summarized in Table B.5.2.

These criteria apply 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.

Table B.5.2
Overview of Performance Qualification Test Requirements

B.5.2.1 Verification Tests for Baseline Metrics B 5.2.1.1 Proof pressure test B 5.2.1.2 Baseline Initial Burst Pressure (performed on the inner tank)
B.5.2.2 Verification of Material Compatibility
B.5.2.3 Verification for Expected On-road Performance B.5.2.3.1 Boil-off test B.5.2.3.2 Leak test B.5.2.3.3 Vacuum loss test
B.5.2.4 Verification Test for Service Terminating Performance in Fire

B.5.2.1 Verification for Baseline Metrics

B.5.2.1.1 Proof pressure test

A system will be pressurized to a pressure $p_{test} \geq 1.3$ (MAWP + 0.1 MPa) in accordance with test procedure B.6.3.1.1 without visible deformation, degradation of container pressure, or detectable leakage.

B.5.2.1.2 Baseline Initial Burst Pressure

The burst test shall be performed per the test procedure in B.6.3.1.2 on one sample of the inner container that is not integrated in its outer jacket and not insulated.

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

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

or

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

B.5.2.2 Verification for Material Compatibility

The manufacturer has to ensure to use compatible material in his application.
For definition of test procedures in order to prove the material compatibility see B.6.3.2.
⇒⇒BMW/GWS to draft B.6.3.2.

B.5.2.3 Verification for Expected On-road Performance

B.5.2.3.1 Boil-off test

The boil-off test shall be performed on a liquid hydrogen storage system equipped with all components as described in A.3.3.2.2 (Figure 4). The test shall be performed on a system filled with liquid hydrogen per the test procedure in B.6.3.3.1 and demonstrate that the boil-off system limits the pressure in the inner storage container below the maximum allowable working pressure.

B.5.2.3.2 Leak test

After the boil-off test in B.5.2.3.1, the system shall be kept at boil-off pressure and the total discharge rate due to leakage shall be measured per the test procedure in B.6.3.3.2. The maximum allowable discharge from the hydrogen storage system 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.] (see B.6.2.3.4. test procedure).

B.5.2.3.3 Vacuum loss test

The vacuum loss test shall be performed on a liquid hydrogen storage system equipped with all components as described in A.3.3.2.2 (Figure 4). The test shall be performed on a system filled with liquid hydrogen per the test procedure in B.6.3.3.3 and demonstrate that both primary and secondary pressure relief devices limit the pressure to the values specified in B.6.3.3.3 in case vacuum pressure is lost .

B.5.2.4 Verification Test for Service Terminating Conditions

At least one system must demonstrate the working of the pressure relief devices and the absence of rupture under the following service-terminating conditions. Specifics of test procedures are provided in Section 6.3.4.

A hydrogen storage system will be filled to half-full liquid level and exposed to fire in accordance with test procedure 6.3.4. The pressure relief device(s) will release the contained gas in a controlled manner without rupture.

For steel containers the test is passed when the requirements relating to the pressure limits for the pressure relief devices as described in B.6.3.3.3 are fulfilled. For other container materials, an equivalent level of safety shall be demonstrated.
SGS-10 >> Is localized fire needed for LH container?

B.5.3 VEHICLE FUEL SYSTEM.
This section specifies requirements for the integrity of the hydrogen fuel delivery system, which includes the hydrogen storage system, piping, joints, and components in which hydrogen is present.

B.5.3.1 In-use Fuel System Integrity:

B.5.3.1.1 Fueling receptacle

a) A compressed hydrogen fueling receptacle shall prevent reverse flow to the atmosphere (test procedure B.6.1.6).

b) Fueling receptacle label: A label shall be provided close to the fueling receptacle, for example, inside a refilling hatch, showing the following information:
   i. For compressed hydrogen storage system: Fuel type, NWP, date of removal from service of containers.
   ii. For liquefied hydrogen storage system: Fuel type.

B.5.3.1.2 Hydrogen discharge systems

B.5.3.1.2.1 Pressure relief systems (test procedure B.6.1.6)

a) TPRDs and PRDs. The outlet of the vent line, if present, for hydrogen gas discharge from TPRD(s) and/or PRD(s) of the storage system shall be protected, e.g. by a cap.
b) TPRDs. The hydrogen gas discharge from TPRD(s) of the storage system shall not be directed:
   - into enclosed or semi-enclosed spaces.
   - into or towards any vehicle wheel housing
   - towards hydrogen gas containers
   - forward from the vehicle, or horizontally (parallel to road) from the back or sides of the vehicle
c) Other pressure relief devices (such as a burst disk). The hydrogen gas discharge from other pressure relief devices shall not be directed:
   - towards exposed electrical terminals, exposed electrical switches or other ignition sources
   - into or towards the vehicle passenger or cargo compartments
   - into or towards any vehicle wheel housing
   - towards hydrogen gas containers

B.5.3.1.2.2 Fuel cell / vehicle exhaust system. At the 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 any time (B.6.1.4 test procedure).

B.5.3.1.3 Protection against Flammable Conditions: Single Failure Conditions

B.5.3.1.3.1 Hydrogen leakage and/or permeation from the hydrogen storage system shall not be allowed to directly vent to the passenger, luggage, or cargo compartments, or to any enclosed or semi-enclosed spaces within the vehicle that contain unprotected ignition sources

B.5.3.1.3.2 Any single failure downstream of the main hydrogen shut off valve shall not result in a hydrogen concentration in air greater than 4% by volume in the passenger compartment.

B.5.3.1.3.3 If during operation, a single failure 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 valve shall be closed to isolate the system and a warning shall be provided (per B.5.3.1.5).

B.5.3.1.4 Fuel System Leakage. The hydrogen fueling line and the hydrogen system(s) downstream of the main shut off valve(s) shall not leak. Compliance shall be verified at NWP (B.6.1.5 test procedure).

B.5.3.1.5 Tell-tale warning to driver

The warning shall be given by a tell-tale(s) or display text with the following properties:

a. Shall be visible to the driver while in the driver's designated seating position with the driver's seat belt fastened.
b. Shall be yellow in color if the detection system malfunctions and shall be red in compliance with section B.5.3.1.3.3.
c. When illuminated, shall be visible to the driver under both daylight and night time driving conditions.
d. Shall remain continuously illuminated while the cause (4% concentration or detection malfunction) exists and the ignition locking system is in the "On" ("Run") position or the propulsion system is activated.
e. Shall extinguish at the next propulsion system start cycle only if the cause for alerting the driver has been corrected

B.5.3.2 Post-Crash Fuel System Integrity

B. 5.3.2.1 Fuel leakage limit: the volumetric flow of hydrogen gas leakage shall not exceed an average of 118 NL per minute for 60 minutes after the crash (in B.6.1.1 test procedures) for vehicles with either Compressed Hydrogen Storage Systems or Liquefied Hydrogen Storage Systems.

B.5.3.2.2 Concentration limit in enclosed spaces: The hydrogen fuel leakage shall not result in a hydrogen concentration in air greater than 4% by volume in the passenger, luggage and cargo compartments (B.6.1.2 test procedures) for vehicles with either Compressed Hydrogen Storage Systems or Liquefied Hydrogen Storage Systems.

B.5.4 Electric Safety

B.5.4.1 Electric Safety Requirements - in-use

B.5.4.1.1 General

Paragraph B.5.4.1 applies to the electric power train of fuel cell vehicles equipped with one or more traction motor(s) operated by electric power and not permanently connected to the grid, as well as their high voltage components and systems which are conductively connected to the high voltage bus of the electric power train.

B.5.4.1.2 Requirements for Protection against Electrical Shock

B.5.4.1.2.0 Protection against electric shock

These electrical safety requirements apply to high voltage buses under conditions where they are not connected to external high voltage power supplies.

B.5.4.1.2.1 Protection against direct contact

The protection against direct contact with live parts shall comply with paragraphs B.5.4.1.2.1.1 and B.5.4.1.2.1.2. These protections (solid insulator, electrical protection barrier, enclosure, etc.) shall not be able to be opened, disassembled or removed without the use of tools.

B.5.4.1.2.1.1 For protection of live parts inside the passenger compartment or luggage compartment, the protection degree IPXXD shall be provided.

B.5.4.1.2.1.2 For protection of live parts in areas other than the passenger compartment or luggage compartment, the protection degree IPXXB shall be satisfied.

B.5.4.1.2.1.3 Connectors

Connectors (including vehicle inlet) are deemed to meet this requirement if:

a) they comply with B.5.4.1.2.1.1 and B.5.4.1.2.1.2 when separated without the use of tools or
b) they are located underneath the floor and are provided with a locking mechanism or
c) they are provided with a locking mechanism and other components shall be removed with the use of tools in order to separate the connector or
d) the voltage of the live parts becomes equal or below DC 60V or equal or below AC 30V (rms) within 1 second after the connector is separated

B.5.4.1.2.1.4 Service disconnect

For a service disconnect which can be opened, disassembled or removed without tools, it is acceptable if protection degree IPXXB is satisfied under a condition where it is opened, disassembled or removed without tools.

B.5.4.1.2.1.5 Marking

B.5.4.1. 2.1.5.1 The symbol shown in Figure 1 shall appear on or near the RESS. The symbol background shall be yellow, the bordering and the arrow shall be black.

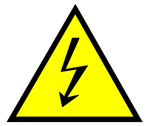


Figure 1 — Marking of high voltage equipment

B.5.4.1.2.1.5.2 The symbol shall be visible on enclosures and electrical protection barriers, which, when removed expose live parts of high voltage circuits. This provision is optional to any connectors for high voltage buses. This provision shall not apply to any of the following cases

a) where electrical protection barriers or enclosures cannot be physically accessed, opened, or removed; unless other vehicle components are removed with the use of tools.

b) where electrical protection barriers or enclosures are located underneath the vehicle floor

B.5.4.1. 2.1.5.3 Cables for high voltage buses which are not located within enclosures shall be identified by having an outer covering with the colour orange.

B.5.4.1.2.2 Protection against indirect contact

B.5.4.1.2.2.1 For protection against electrical shock which could arise from indirect contact, the exposed conductive parts, such as the conductive electrical protection barrier and enclosure, shall be conductively connected securely to the electrical chassis by connection with electrical wire or ground cable, or by welding, or by connection using bolts, etc. so that no dangerous potentials are produced.

B.5.4.1.2.2.2 The resistance between all exposed conductive parts and the electrical chassis shall be lower than 0.1 ohm when there is current flow of at least 0.2 amperes. Demonstrated by using one of the test procedures described in B.6.4.4.

This requirement is satisfied if the galvanic connection has been established by welding. In case of doubts a measurement shall be made.

B.5.4.1.2.2.3 In the case of motor vehicles which are connected to the grounded external electric power supply through the conductive connection, a device to enable the conductive connection of the electrical chassis to the earth ground shall be provided.

The device shall enable connection to the earth ground before exterior voltage is applied to the vehicle and retain the connection until after the exterior voltage is removed from the vehicle.

Compliance to this requirement may be demonstrated either by using the connector specified by the car manufacturer, or by analysis (e.g. visual inspection, drawings etc.).

B.5.4.1.2.3 Isolation Resistance

B.5.4.1.2.3.1 In fuel cell vehicles, DC high voltage buses shall have an on-board isolation resistance monitoring system together with a warning to the driver if the isolation resistance drops below the minimum required value of 100 ohms/volt.

The function of the on-board isolation resistance monitoring system shall be confirmed as described in B.6.4.2.

The isolation resistance between the high voltage bus of the coupling system for charging the RESS, which is not energized in conditions other than that during the charging of the RESS, and the electrical chassis need not to be monitored.

B.5.4.1.2.3.2 Electric power train consisting of separate Direct Current or Alternating Current buses

If AC high voltage buses and DC high voltage buses are conductively isolated from each other, isolation resistance between the high voltage bus and the electrical chassis shall have a minimum value of 100 ohms/volt of the working voltage for DC buses, and a minimum value of 500 ohms/volt of the working voltage for AC buses.

The measurement shall be conducted according to B.6.4.1 “Isolation Resistance Measurement Method”.

[B.5.4.1.2.3.3 Electric power train consisting of combined DC- and AC-buses

However, if all AC high voltage buses are protected by one of the 2 following measures, isolation resistance between the high voltage bus and the electrical chassis shall have a minimum value of 100 ohms/volt of the working voltage.

a) double or more layers of solid insulators, electrical protection barriers or enclosures that meet the requirement in paragraph **B.5.4.1.2.2** independently, for example wiring harness;

b) mechanically robust protections that have sufficient durability over vehicle service life such as motor housings, electronic converter cases or connectors.]

Comment: OICA has to come up with a proposal for a) and b) that allows NHTSA can tell the manufacturer how the system has to be tested.

B.5.4.1.2.3.4 Isolation resistance requirement for the coupling system for charging the RESS

For the vehicle inlet intended to be conductively connected to the grounded external AC power supply and the electrical circuit that is conductively connected to the vehicle inlet during charging the RESS, the isolation resistance between the high voltage bus and the electrical chassis shall be at least 1M ohms when the charger coupler is disconnected. During the measurement, the RESS may be disconnected.

The measurement shall be conducted according to B.6.4.1 “Isolation Resistance Measurement Method”

B.5.4.1.3 Functional Safety

At least a momentary indication shall be given to the driver when the vehicle is in "active driving possible mode".

However, this provision does not apply under conditions where an internal combustion engine provides directly or indirectly the vehicle´s propulsion power upon start up.

When leaving the vehicle, the driver shall be informed by a signal (e.g. optical or audible signal) if the vehicle is still in the active driving possible mode.

If the on-board RESS can be externally charged, vehicle movement by its own propulsion system shall be impossible as long as the connector of the external electric power supply is physically connected to the vehicle inlet.
This requirement shall be demonstrated by using the connector specified by the car manufacturer.

The state of the drive direction control unit shall be identified to the driver

B.5.4.2 Electric safety requirements – post-crash

B.5.4.2.1. General

Fuel cell vehicles equipped with electric power train shall meet the requirements of paragraph B.5.4.2.2. through B.5.4.2.4. This can be met by a separate impact test provided that the electrical components do not influence the occupant protection performance of the vehicle type as defined in the impact regulation. In case of this condition the requirements of paragraph B.5.4.2.2. through B.5.4.2.4 shall be checked in accordance with the methods set out in B.6.4.5.

B.5.4.2.2 Protection against electrical shock

After the impact at least one of the three criteria specified in paragraph B.5.4.2.2.1 through paragraph B.5.4.2.2.3 shall be met. However Contracting Parties under the 1998 Agreement can choose to adopt Paragraph B.5.4.2.2.4 “Low electrical energy” as additional criteria.

If the vehicle has an automatic disconnect function, or device(s) that conductively divide the electric power train circuit during driving condition, at least one of the following criteria shall apply to the disconnected circuit or to each divided circuit individually after the disconnect function is activated.
However criteria defined in B.5.4.2.2.2 shall not apply if more than a single potential of a part of the high voltage bus is not protected under the conditions of protection IPXXB.

In the case that the test is performed under the condition that part(s) of the high voltage system are not energized, the protection against electrical shock shall be proved by either B.5.4.2.2.2 or [B.5.4.2.2.3] for the relevant part(s).

B.5.4.2.2.1 Absence of high voltage

The voltages Vb, V1 and V2 of the high voltage buses shall be equal or less than 30 VAC or 60 VDC within 60 seconds after the impact as specified in B.6.4.5 paragraph B.6.4.5.2.22.

B.5.4.2.2.2 Isolation resistance

The criteria specified in the paragraphs B.5.4.2.2.2.1 and B.5.4.2.2.2.2 below shall be met. The measurement shall be conducted in accordance with paragraph B.6.4.5.2.3 of B.6.4.5.

B.5.4.2.2.2.1 Electrical power train consisting of separate DC- and AC-buses

If the AC high voltage buses and the DC high voltage buses are conductively isolated from each other, isolation resistance between the high voltage bus and the electrical chassis (Ri, as defined in paragraph B.6.4.5 .2.3 of B.6.4.5**)** shall have a minimum value of 100 Ω/volt of the working voltage for DC buses, and a minimum value of 500 Ω/volt of the working voltage for AC buses.

B.5.4.2.2.2.2 Electrical power train consisting of combined DC- and AC-buses

If the AC high voltage buses and the DC high voltage buses are conductively connected they shall meet one of the following requirements:

(a) isolation resistance between the high voltage bus and the electrical chassis (Ri, as defined in paragraph B.6.4.5.2.3 of B.6.4.5) shall have a minimum value of 500 Ω/volt of the working voltage.

(b) isolation resistance between the high voltage bus and the electrical chassis (Ri, as defined in paragraph B.6.4.5.2.3 of B.6.4.5) shall have a minimum value of 100 Ω/volt of the working voltage and the AC bus meets the physical protection as described in B.5.4.2.2.3.

(c) isolation resistance between the high voltage bus and the electrical chassis (Ri, as defined in paragraph B.6.4.5.2.3 of B.6.4.5) shall have a minimum value of 100 Ω/volt of the working voltage and the AC bus meets the absence of high voltage as described in B.5.4.2.2.1.

[B.5.4.2.2.3 Physical Protection

For protection against direct contact with high voltage live parts, the protection IPXXB shall be provided.

In addition, for protection against electrical shock which could arise from indirect contact, the resistance between all exposed conductive parts and electric chassis shall be lower than 0.1 ohm when there is current flow of at least 0.2 amperes.

This requirement is satisfied if the galvanic connection has been established by welding. In case of doubts a measurement shall be made.]

B.5.4.2.2.4 Low electrical energy

The total energy (TE) on the high voltage buses shall be less than [2.0] Joules when measured according to the test procedure as specified in paragraph B.6.4.5 .2.5 of B.6.4.5with the formula (a). Alternatively the total energy (TE) may be calculated by the measured voltage Vb of the high voltage bus and the capacitance of the X-capacitors (C_x) specified by the manufacturer or determined by measurement according to formula (b) of paragraph B.6.4.5 .2.5 of B.6.4.5.

The energy stored in the Y-capacitors (TE_{y1}, TE_{y2}) shall also be less than [2.0] Joules. This shall be calculated by measuring the voltages V1 and V2 of the high voltage buses and the electrical chassis, and the capacitance of the Y-capacitors specified by the manufacturer or determined by measurement according to formulas (c) of paragraph B.6.4.5 .2.5 of B.6.4.5.

B.5.4.2.3 Electrolyte spillage

In the period from the impact until 30 minutes after no electrolyte from the RESS shall spill into the passenger compartment and no more than 7 per cent of electrolyte shall spill from the RESS ~~except open type traction batteries~~ outside the passenger compartment~~. For open type traction batteries no more than 7 per cent with a maximum of 5.0 liters shall spill outside the passenger compartment.~~

The manufacturer shall demonstrate compliance in accordance with paragraph B.6.4.5.2.6 of B.6.4.5.

B.5.4.2.4 RESS retention

RESS located inside the passenger compartment shall remain in the location in which they are installed and RESS components shall remain inside RESS boundaries.

No part of any RESS that is located outside the passenger compartment for electric safety assessment shall enter the passenger compartment during or after the impact test.

The manufacturer shall demonstrate compliance in accordance with paragraph B.6.4.5.2.7 of B.6.4.5.

B.6. TEST CONDITIONS AND PROCEDURES

B.6.1 Compliance Tests for Fuel System Integrity

B.6.1.1 Post-Crash Leak Test

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

To evaluate possible hydrogen discharge following the vehicle crash tests, the following procedure should be used depending whether vehicles contain Compressed Hydrogen Storage Systems or Liquefied Hydrogen Storage Systems and the selection of fluid in the storage systems for the crash test.

B.6.1.1.1 Post-Crash Leak Test -- Compressed Hydrogen Storage System (CHSS)

Prior to conducting the crash test, instrumentation shall be installed in the Compressed Hydrogen Storage System (CHSS) to perform the required pressure and temperature measurements if the standard vehicle does not already have instrumentation with the required accuracy.

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

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

where NWP is the Nominal Working Pressure (MPa) of the CHSS, T_o is the ambient temperature to which the CHSS is expected to settle, and P_{target} is the targeted fill pressure after the CHSS temperature settles.

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

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

B.6.1.1.1.1 Post-Crash Leak Test -- Compressed Hydrogen Storage System (CHSS) Filled with Compressed Hydrogen

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

$$\Delta t = V_{CHSS} \times NWP / 1000 \times ((-0.027 \times NWP + 4) \times R_s - 0.21) - 1.7 \times R_s$$

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

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

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

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

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

where P_0 is the measured initial pressure (MPa), To is the measured initial temperature (^oC), and V_{CHSS} is the volume of the CHSS (L).

Correspondingly, the final mass of hydrogen in the CHSS, M_f, at the end of the time internal (Δt) can be calculated as follows:

$$P_f' = P_f \text{ x } 288 / (273 + T_f)$$

$$\rho_f' = -0.0027 \text{ x } (P_f')^2 + 0.75 \text{ x } P_f' + 0.5789$$

$$M_f = \rho_f' \text{ x } V_{CHSS}$$

where P_f is the measured final pressure (MPa) at the end of the time interval, Tf is the measured final temperature (C), and V_{CHSS} is the volume of the CHSS (L).

The average hydrogen flow rate over the time interval (that shall be less than the criteria in B.5.3.2.1) is therefore

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

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

B.6.1.1.1.2 Post-Crash Leak Test -- Compressed Hydrogen Storage System (CHSS) Filled with Compressed Helium

The helium gas pressure (P_0) and temperature (T_0) shall be measured immediately before the impact and then at a predetermined time interval after the impact. The predetermined time interval starts when the vehicle comes to rest after the impact and continues for at least 60 minutes. In order to accommodate large volume CHSSs operating up to 70MPa, it may be to extend the time interval (Δt) so that the pressure loss over the time interval can be accurately measured. The time interval can be determined from the follow equation:

$$\Delta t = V_{CHSS} \text{ x } NWP / 1000 \text{ x } ((-0.028 \text{ x } NWP + 5.5) \text{ x } R_s - 0.3) - 2.6 \text{ x } R_s$$

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

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

$$P_o' = P_o \text{ x } 288 / (273 + T_0)$$

$$\rho_o' = -0.0043 \text{ x } (P_0')^2 + 1.53 \text{ x } P_0' + 1.49$$

$$M_o = \rho_o' \text{ x } V_{CHSS}$$

where P_0 is the measured initial pressure (MPa), To is the measured initial temperature (C), and V_{CHSS} is the volume of the CHSS (L).

Correspondingly, the final mass of hydrogen in the CHSS at the end of the time internal (Δt) can be calculated as follows:

$$P_f' = P_f \text{ x } 288 / (273 + T_f)$$

$$\rho_f' = -0.0043 \text{ x } (P_f')^2 + 1.53 \text{ x } P_f' + 1.49$$

$$M_f = \rho_f' \text{ x } V_{CHSS}$$

where P_f is the measured final pressure (MPa) at the end of the time interval, T_f is the measured final temperature (C), and V_{CHSS} is the volume of the CHSS (L).

The average helium flow rate over the time interval is therefore

$$V_{He} = (Mf\text{-}Mo) / \Delta t \text{ x } 22.41 / 4.003 \text{ x } (P_o/ P_{target})$$

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

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

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

where V_{H2} is the corresponding average volumetric flow of hydrogen (that shall be less than the criteria in B.5.3.2.1 to pass).

B.6.1.1.2 Post-Crash Leak Test -- Liquid Hydrogen Storage:

Prior to the crash test, if a helium pressure test of the liquefied hydrogen storage system (LHSS) is planned after the crash and if the vehicle does not already have the following capabilities as part of the standard vehicle, the following equipment shall be installed:

1) LHSS Pressure Sensor. The pressure sensor shall have a full scale of reading of at least 150% of MAWP, an accuracy of at least 1% of full scale, and capable of reading values of at least 10 KPa.

2) LHSS Temperature Sensor. The temperature sensor shall be capable of measure cryogenic temperatures expected before crash. The sensor shall be located on an outlet, as near as possible to the tank.

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

Following completing LHSS preparation and prior to the vehicle crash test, the LHSS shall be purged, if necessary, following manufacturing directions to remove impurities from the tank before filling with liquefied fluid. The LHSS shall then be filled with either liquefied hydrogen (LH2) to the maximum quantity or liquefied nitrogen (LN2) to at least 10% of the maximum liquefied hydrogen volume in the LHSS, depending which fluid is planned for the crash test.

After completing the fill, the leak-tightness of the LHSS shall be confirmed and the LHSS shall be allowed to equilibrate. After the LHSS pressure and temperature sensors indicate that the system has cooled and equilibrated, the vehicle shall be crashed per state or regional regulation.

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.

Following the crash, there shall be no visible leak of cold gas or liquid for a period of at least 1 hour after the crash. Additionally, the operability of the pressure controls or Pressure Relief Devices (PRDs) shall be proven to ensure that the LHSS is protected against burst after the crash. If the LHSS vacuum has not been compromised by the crash, nitrogen gas may be added to the LHSS via the fill / drain port until pressure controls and/or PRDs are activated. In the case of re-closing pressure controls or PRDs, activation and re-closing for at least 2 cycles shall be proven.

Following confirmation that the pressure control and/or safety relief valves are still functional, a leak test shall be conducted on the LHSS using the procedures in either B.6.1.1.2.1 or B.6.1.1.2.2.

B.6.1.2 Post-Crash System Integrity -- Concentration Test for Enclosed Spaces

B.6.1.2.1 Post-Crash Test of Enclosed Spaces – Compressed Hydrogen Storage

The measurements shall be recorded in the crash test that evaluates potential hydrogen (or helium) leakage (test procedure B.6.1.1.1).

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

Calibrate sensors to traceable references to ensure an accuracy of $\pm$5% at the targeted criteria of 4% hydrogen or 3% helium by volume in air, and a full scale measurement capability of at least

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

Prior to the crash impact, the sensors shall be located in the passenger, luggage, and cargo compartments of the vehicle as follows:

1) At a distance within 250 mm of the headliner above the driver's seat or near the top center the passenger compartment.

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

3) At a distance within 100 mm of the the top of luggage and cargo compartments within the vehicle *that are not directly effected by the particular crash impact to be conducted.*

The sensors shall be securely mounted to the vehicle structure or seats and protected for the planned crash test from debri, air bag exhaust gas and projectiles. The measurements following the crah shall be recorded by instruments located within the vehicle or by remote transmission.

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

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

The filtered readings from each sensor shall be below the targeted criteria of 4% for hydrogen and 3% for helium at all times throughout the 60 minute post-crash test period.

B.6.1.2.2 Post-Crash Enclosed Spaces Test -- Liquid Hydrogen Storage System (LHSS)

The measurements shall be recorded in the crash test that evaluates potential liquid hydrogen leakage in test procedure B.6.1.1.2 if the LHSS contains hydrogen for the crash test or during the helium leak test in test procedure B.6.1.1.2.1.

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

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

The installation in vehicles with LHSSs shall meet the same requirements as for vehicles with CHSSs.

Data from the sensors shall be collected at least every 5 seconds and continue for a period of 60 minutes after the vehicle comes to a rest if post-crash hydrogen is being measured or after the initiation of the helium leak test if helium buildup is being measured. Up to a 5 second rolling average may be applied to the measurements to provide “smothing” and filter effects of spurious data points. The rolling average of each sensor shall be below the targeted criteria of 4% hydrogen (for a test with liquefied hydrogen) or 0.8% helium by volume in air (for a test at room temperature with helium) at all times throughout the 60 minute post-crash test period.

B.6.1.3 Compliance Test for Single Failure Conditions

B.6.1.3.1 Alternative Test Procedure for Vehicle Equipped with Hydrogen Sensors

B.6.1.3.1.1 Test Condition

B.6.1.3.1.1a Test vehicle. Start the propulsion system of the test vehicle, warm it up to its normal operating temperature and leave it operating for the test duration. If the vehicle is not a fuel cell vehicle, warm it up and keep it idling. If the test vehicle has a system to stop idling automatically, measures shall be taken so as to prevent the engine from stopping.

B.6.1.3.1.1b Test gas. Mixture of air and hydrogen gas with 4% hydrogen or a lower concentration shall be used. The proper concentration should be selected based on the recommendation (or the detector specification) by the manufacturer.

B.6.1.3.1.2 Test method.

B.6.1.3.1.2a Preparation for the test. The test shall be conducted without any influence of wind. If necessary for blowing the test gas to the hydrogen gas leakage detector without fail, the following measures shall be taken.

- Attach a test gas induction hose to the hydrogen gas leakage detector.
- Enclose the hydrogen leak detector with a cover to make gas stay around hydrogen leak detector.

B.6.1.3.1.2b Execution of test.

- 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.
- Blow test gas to the hydrogen gas leakage detector.
- Confirm the warning provided
- Confirm the main shut-off valve closed. To confirm the operation of the main shut-off valve of the hydrogen supply, the monitoring of the electric power to the shut-off valve or of the sound of the shut-off valve activation may be used.

B.6.1.3.2 Test Procedure for Vehicle Not Equipped with Hydrogen Sensors.

B.6.1.3.2.1 Preparation:

B.6.1.3.2.1.a The test shall be conducted without any influence of wind.

B.6.1.3.2.1.b Special attention shall be paid to the test environment as during the test flammable mixtures of hydrogen and air may occur.

B.6.1.3.2.1.c Prior to the test the vehicle shall 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.

B.6.1.3.2.1.d Only for the purpose of the test hydrogen concentration detectors shall be installed in enclosed or semi enclosed volumes on the vehicle.

If bulkheads or similar structures are provided to prevent hydrogen from intruding into passenger compartments, it is not necessary to have hydrogen concentration measurement points in the passenger compartments. An example of hydrogen concentration measurement locations can be found in the document "Examples of hydrogen concentration measurement points for testing" – need reference.

SGS – this test provides no measurement in the passenger compartment
SGS – this test provides no confirmation of a warning tell-tale or vehicle shut-down if concentration exceeds 4% in an enclosed space

B.6.1.3.2.2 Procedure:

B.6.1.3.2.2.a Vehicle doors, windows and other covers shall be closed.

B.6.1.3.1.2.b Start the propulsion system, allow it to warm up to its normal operating temperature and leave it operating at idle for the test duration.

B.6.1.3.2.2.c A leak shall be simulated using the remote controllable function.

B.6.1.3.2.2.d 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.

B.6.1.3.2.2.e If during the test the hydrogen concentration at one of the measurement locations exceeds 4% significantly, the test shall be terminated

⇒⇒**SGS-9:** OICA will look for a test report on the conduct of the test described in B.6.1.3.1

B.6.1.4 Compliance Test for the ~~Fuel Cell~~ Vehicle Exhaust System

B.6.1.4.a The ~~fuel cell~~ power system of the test vehicle (e.g., fuel cell stack or engine) shall be warmed up to its normal operating temperature.

B.6.1.4.b The measuring device shall be warmed up before use to its normal operating temperature.

B.6.1.4.c The measuring section of the measuring device shall be placed on the centre line of the exhaust gas flow within 100 mm from the exhaust gas outlet external to the vehicle.

B.6.1.4.d The exhaust hydrogen concentration shall be continuously measured during the following steps::

- Shut down the power system
- Upon completion of the shut-down process, immediately start the power system.
- After a lapse of one minute, turn off the system and continue the measurement until the fuel cell system shut down procedure is completed.

B.6.1.4.e The measurement device must have a measurement response time of less than 300 milliseconds.

B.6.1.5 Compliance Test for Fuel Line Leakage

B.6.1.5.a The power system of the test vehicle (e.g., fuel cell stack or engine) shall be warmed up and operating at its normal operating temperature with the operating pressure applied to fuel lines

B.6.1.5.b Hydrogen leakage shall be evaluated at accessible sections of the fuel lines from the high-pressure section to the fuel cell stack (or the engine), using a gas detector or leak detecting liquid, such as soap solution.

B.6.1.5.c Hydrogen leak detection shall be performed primarily at joints

B.6.1.5.e When a gas leak detector is used, detection shall be performed by operating the leak detector for at least 10 seconds at locations as close to fuel lines as possible.

B.6.1.5.f When a leak detecting liquid is used, hydrogen gas leak detection shall be performed immediately after applying the liquid. In addition, visual checks shall be performed a few minutes after the application of liquid in order to check for bubbles caused by trace leaks.

B.6.1.6 Installation verification: The system shall be visually inspected for compliance per sections B.5.3.1.1 and B 5.3.1.2.1.

B.6.2 TEST PROCEDURES FOR COMPRESSED HYDROGEN STORAGE

B.6.2.1 Material Qualification

B.6.2.1.1 Material Tests for Conformity of Production

B.6.2.1.1.a Plastic liner tensile test. For containers with plastic liners, two plastic liners shall be tested at -40C in accordance with ISO 527-2. The tensile yield strength and ultimate elongation shall be within the manufacturer's specifications.

B.6.2.1.1.b 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 temperature shall be greater than or equal to 100C.

B.6.2.1.1.c 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.

B.6.2.1.1.d Resin shear strength test. For containers with composite wraps, resin materials shall be tested on a coupon of the over-wrap in accordance with ASTM D2344. After boiling in water for 24 hours the minimum shear strength of the composite shall be 13.8MPa.

B.6.2.1.1.e 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 -20C; the coating shall exhibit no apparent 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 rating 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.

B.6.2.1.1.f Metal tensile strength and elongation. Documentation of tensile strength and elongation testing shall confirm that materials meet the manufacturer's specifications.

a) For steel alloys, tensile strength and elongation tests should be conducted on a finished steel unit (containment vessel or liner) that comes in contact with hydrogen in the interior of a high pressure containment vessel according to tensile strength and elongation tests in 10.2-10.4 of ISO 9809-1:1999 or ISO 9809-2:2000. Demonstrated tensile strength and elongation shall meet the manufacturer's design specifications. For containment vessels without full composite fiber/resin structural wraps, it is recommended that the elongation be at least 14%.

b) For aluminum alloys, material tests should be conducted on a finished aluminum alloy unit (containment vessel or liner) that comes in contact with hydrogen in the interior of a high pressure containment vessel according to 10.2 – 10.3 and Annexes A or B of ISO 7866:1999. (These are tensile, corrosion and load cracking tests; corrosion tests are not required). Demonstrated tensile strength and elongation shall meet the manufacturer's design specifications. For containment vessels without full composite fiber/resin structural wraps, it is recommended that the elongation be at least 12%. Welded liners should follow guidance in 7.2.3 – 7.2.7 and Annexes A or B (except B2.2) of EN 12862:2000. (These are tensile and flexibility tests.)

B.6.2.1.2 Hydrogen Compatibility (Embrittlement)

a) Steel

In all applications where steel comes in contact with hydrogen, hydrogen compatibility should be demonstrated. Steels that meet the requirements of Sections B.6.3 and B.7.2.2 of ISO 9809-1:1999 are recognized as hydrogen compatible for low stress applications.

The following steel alloys are recognized as suitable for use in contact with hydrogen at pressures up to 100 MPa: UNS S31600 and UNS S31603 (equivalents include

SUS316L, AISI316L, AISI316 and DIN1.4435) but all must have $\geq$ 12% nickel composition and $\leq$ 0.1% magnetic phases by volume as measured by ferritiscope. These steel applications may not include welds.

⇒⇒SGS-10: Participants will provide comments on the above listed materials

⇒⇒SGS-10: Test procedures for qualification of additional steels are expected to be developed in 2010 by industry standards organizations and presented for inclusion.

b) Aluminum

Aluminum alloys that meet the requirements of Sections 6.1 and 6.2 of ISO 7866:1999 are recognized as hydrogen compatible for low stress applications.

The following aluminum alloys are recognized as suitable for use in contact with hydrogen in the hydrogen storage system, as defined in Figure B.5.1.1, or in any other high-stress applications in contact with hydrogen: A6061-T6, A6061-T62, A6061-T651 and A6061-T6511. These aluminum applications may not include welds.

⇒⇒SGS-10: Participants will provide comments on the above listed materials

⇒⇒SGS-10: Test procedures for qualification of additional alluminum alloys are expected to be developed in 2010 by industry standards organizations and presented for inclusion.

B.6.2.1.3 Stress Rupture Resistance Test

(1) Three containers made from the new material (e.g., a composite fiber reinforced polymer) shall be burst; the burst pressures shall be within $\pm$10% of the midpoint, BPo, of the intended application. Then,
- Three containers shall be held at $\geq$ 80% BPo and at 65 ($\pm$5)^{o}C; they shall not rupture within 100 hrs; the time to rupture shall be recorded.
- Three containers shall be held at $\geq$ 75% BPo and at 65 ($\pm$5)^{o}C; they shall not rupture within 1000hrs; the time to rupture shall be recorded.
- Three containers shall be held at $\geq$ 70% BPo and at 65 ($\pm$5)^{o}C; they shall not rupture within one year.
- The test shall be discontinued after one year. Each container that has not ruptured within the one year test period shall undergo a burst test, and the burst pressure shall be recorded.

(2) The container diameter shall be $\geq$ 50% of the diameter of intended application and of comparable construction. The tank may have a filling (to reduce interior volume) if >99% of the interior surface area remains exposed.

(3) Containers constructed of carbon fiber composites and/or metal alloys are excused from this test.

(4) Containers constructed of glass fiber composites that have an initial burst pressure $\geq$ 330% NWP are excused from this test, in which case BP_{min} = 330% NWP shall be applied in B.5.1.1.1 (Baseline Initial Burst Pressure) and in B.7.1.3.ii(a) (Verification Test for Conformity of Production).

B.6.2.2 Test Procedures for Baseline Performance Metrics (B.5.1.1)

B.6.2.2.1 Burst Test (Hydraulic). The burst test shall be conducted at 20 ($\pm$5)^{o}C using a non-corrosive fluid. The rate of pressurization shall be less than or equal to 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.

B.6.2.2.2 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 and fluid at the specified temperature and relative humidity at the start of testing; maintain the environment, fueling fluid and container skin at the specified temperature for the duration of the testing. The container temperature may vary from the environmental temperature during testing.
c) Pressure cycle between less than 2 MPa and the target pressure at a rate not exceeding 10 cycles per minute for the specified number of cycles.
d) Maintain and monitor the temperature of the hydraulic fluid within the container at the specified temperature.

B.6.2.3 Test Procedures for Performance Durability (B.5.1.2)

B.6.2.3.1 Proof Pressure Test. The system should be pressurized smoothly and continually with a non-corrosive hydraulic fluid 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.

B.6.2.3.2 Drop (Impact) Test (Unpressured). One or more storage containers will be drop tested without internal pressurization or attached valves. All drop tests may be performed on one container, or individual impacts on a maximum of 3 containers. The surface onto which the containers are dropped should be a smooth, horizontal concrete pad or similar flooring. The container(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 container 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 containers rotate the container 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. The drop pattern is illustrated below.

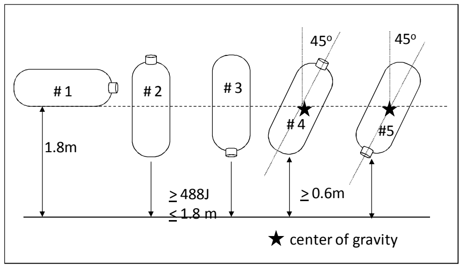


Figure B.6.2.3.2

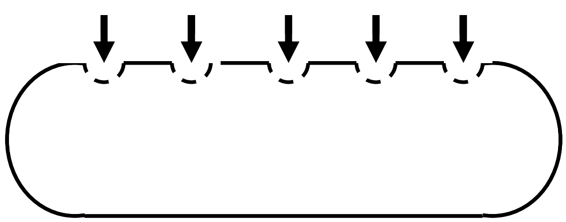
No attempt should be made to prevent the bouncing of containers, but the containers may be prevented from falling over during the vertical drop test described in b) above.

Following the drop impact, the container that has been subjected to the 45^{o} impacts should then be subjected to further testing as specified in B.5.2.2. The container(s) subjected to horizontal and vertical drop impacts, if different from the container subjected to a 45^{o} drop impacts, should be subjected to 1000 hydraulic pressure cycles at 20 ($\underline{+}$5)^{o}C per the test procedure defined in B.6.2.2.2.

B.6.2.3.3 Surface Damage Test (Unpressured). 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 unpressurized 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 container. The second cut will be at least 0.75 mm deep and 200 mm long toward the end of the container opposite the valve.

b) Pendulum Impacts: The upper section of the horizontal storage container should be divided into five distinct (not overlapping) areas 100 mm in diameter each (see Figure B.6.2.3.3). 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 container should be 30J. The container should be secured in place during pendulum impacts and not under pressure.



“Side” View of Tank

Figure B.6.2.3.3

B.6.2.3.4 Chemical Exposure and Ambient Temperature Pressure Cycling Test. Each of the 5 areas of the unpressured container preconditioned by pendulum impact (6.4.2.5b) should be exposed to one of five solutions: 1) 19% (by volume) sulfuric acid in water (battery acid), 2) 25% (by weight) sodium hydroxide in water, 3) 5% (by volume) methanol in gasoline (fluids in fueling stations), 4) 28% (by weight) ammonium nitrate in water (urea solution), and 5) 50% (by volume) methyl alcohol in water (windshield washer fluid).

Orient the test container 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.

The exposure of the container with the glass wool should be maintained for 48 hrs with the container held at 125% NWP (applied hydraulically) and 20 ($\pm$5)^{o}C before the container is subjected to further testing.

Perform pressure cycling to the specified target pressures according to B.6.2.2.2 at 20 ($\pm$5)^{o}C for the specified numbers of cycles. Remove the glass wool pads and rinse the container surface with water before conducting the final 10 cycles to specified final target pressure.

B.6.2.3.5 Static Pressure Test (Hydraulic). Pressurize the storage system to the target pressure in temperature-controlled chamber. Hold the temperature of the chamber and the non-corrosive fueling fluid at the target temperature within $\pm$5^{o}C for the specified duration.

B.6.2.4 Test Procedures for Expected On-Road Performance (B.5.1.3)
(Pneumatic test procedures are provided; Hydraulic Test elements are described in 6.4.2)

B.6.2.4.1 Gas Pressure Cycling Test (Pneumatic). At the onset of testing, stabilize the storage system at the specified temperature, relative humidity and fuel level for at least 24 hrs. Maintain the specified temperature and relative humidity 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 less than 2(+1) MPa and the specified maximum pressure. If system controls that are active in vehicle service prevent the pressure from dropping below a specified pressure, the test cycles shall not go below that specified pressure. Control the fill rate to a constant 3-minute pressure ramp rate; control the temperature of the hydrogen fuel dispensed to the container to the specified temperature. Control the defueling rate to greater than or equal to the intended vehicle's maximum fuel-demand rate. Conduct the specified number of pressure cycles. If devices and/or controls are used in the intended vehicle application to prevent an extreme internal temperature, the test may be conducted with these devices and/or controls (or equivalent measures).

B.6.2.4.2 Gas Permeation Test (Pneumatic). A storage system shall be fully filled with hydrogen gas (full fill density equivalent to 100% NWP at 15 °C is 113% NWP at 55 °C) and held at 55°C in a sealed container. The total steady-state discharge rate due to leakage and permeation from the storage system shall be measured.

B.6.2.4.3 Localized Gas Leak Test (Pneumatic). A bubble test may be used to fulfill this requirement. The following guidance is provided for conducting the bubble test:

a. The exhaust of the shutoff valve (and other internal connections to hydrogen systems) shall 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. Note: Visual detection of unacceptable leakage should be feasible. When using standard leak-test fluid, the bubble size is expected to be approximately 1.5 mm in diameter. For a localized rate of 0.005 mg/sec (3.6 mL/min), 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 would be approximately 32 bubbles per minute.

⇒⇒SGS-10: Canada, Japan and GS will review and provide revised text

B.6.2.5 Test Procedures for Service Terminating Performance in Fire (B.5.1.4)

B.6.2.5.1 Fire Test (pneumatic).

The hydrogen container assembly shall consist of the Compressed Hydrogen Storage System (CHSS) with additional relevant features including the venting system (such as the vent line and vent line covering) and any shielding affixed directly to the container (such as thermal wraps of the container(s) and/or coverings/barriers over the TPRD(s)).

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

Method I: Qualification for a Generic (Non-Specific) Vehicle Installation

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

Method 2: Qualification for a Specific Vehicle Installation

If a specific vehicle installation configuration is specified and the qualification of the system is limited to that specific vehicle installation configuration then the test setup may also include additional vehicle componentry in the vehicle-installed configuration. The vehicle componentry, such as shielding or barriers, which are permanently attached to the vehicle's structure by means of welding or bolts and not affixed to the storage system, the test article should include these items in their respective vehicle location. This localized fire test should be conducted on the worst case localized fire exposure areas based on the four fire orientations: fires originating from the direction of the passenger compartment, cargo/luggage compartment, wheel wells or ground-pooled gasoline.

In addition, the container shall be subjected an engulfing fire without any shielding components as described in paragraph B.6.2.5.2.

The following test requirements apply whether either Method 1 or 2 is used to identify the localized fire exposure area(s):

a) Fill the container assembly with compressed hydrogen gas at 100 percent of NWP. The container assembly shall be positioned horizontally approximately 100 mm above the fire source.

⇒⇒ A.4.3(1) suggested as appropriate (PART A) replacement for: "However, contracting party under the 1998 Agreement may choose to use compressed air as an alternative test gas for certification of the container for use in its country or region."

Localized Fire Test

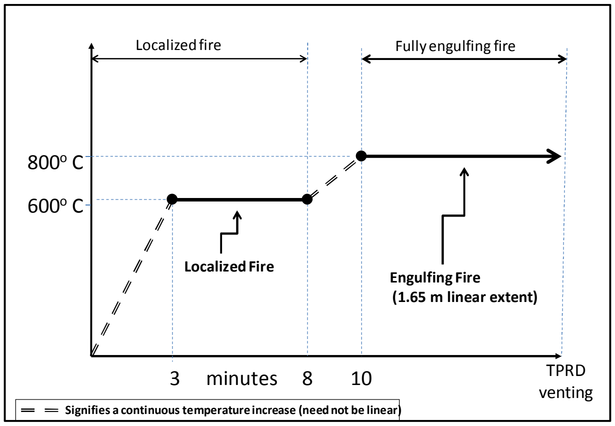
b) The localized fire exposure area, 250mm ± 50mm, shall be the area on the test article furthest from the TPRD(s). If more vulnerable areas are identified for a specific vehicle installation configuration, the area furthest from the TPRD(s) shall be positioned directly over the initial fire source.

c) The fire source shall consist of LPG [~~or other gas~~] burners configured to produce a uniform minimum temperature on the test article defined as a moving 1-minute average per thermocouple with a minimum 5 thermocouples covering the length of the test article up to 1.65m maximum (at least 2 thermocouples within the localized fire area, and at least 3 thermocouples equally spaced and no more than 0.5 m apart in the remaining area) located 25 mm ± 10mm from the outside surface of the test article along its longitudinal axis. At the option of the manufacturer or testing facility, additional thermocouples may be located at TPRD sensing points or any other locations for optional diagnostic purposes.

d) Wind shields shall be applied to ensure uniform heating.

e) The fire source shall initiate within a 250mm ± 50mm longitudinal expanse positioned under the localized exposure area of the test article. The width of the fire source shall encompass the entire diameter (width) of the storage system

f) As shown in the below temperature/time profile, the temperature at the thermocouples in the localized fire area shall be increased continuously to at least 600°C within 3 minutes of ignition, and a temperature of at least 600°C shall be maintained for the next 5 minutes. The temperature outside the region of the initial fire source is not specified during these initial 8 minutes from the time of ignition.



Engulfing Fire Test

g) Then within the next 2-minute interval, the temperature at the thermocouples in the fire source shall be increased to at least 800°C and the fire source shall be extended to produce a uniform temperature along the entire length up to 1.65 meters and the entire width of the test article (engulfing fire).

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

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

B.6.2.5.2 Engulfing fire test:

The test unit is the compressed hydrogen storage system (CHSS). Fill the CHSS with compressed hydrogen gas at 100 percent of NWP. The container vessel shall be positioned horizontally approximately 100 mm above the fire source. Use a uniform fire source that is 1.65 meters long (65 inches). Beginning five minutes after the fire is ignited, maintain an average flame temperature of not less than 590 degrees Celsius as determined by the average of the two thermocouples recording the highest temperatures over a 60 second interval.

this needs to be deleted if TPRD requirements are added for type approval

~~If TPRD has not been qualified in accordance with B.7.1.4.2.1, a second system will be pressurized with hydrogen to 20% of NWP and exposed to an engulfing fire in accordance with test procedure B.6.2.5.2. Temperature-activated pressure relief device shall release the contained gases in a controlled manner. The container shall not rupture.~~

B.6.3. TEST PROCEDURES FOR LIQUEFIED HYDROGEN STORAGE

B.6.3.1 Verification Tests for Baseline Metrics

B.6.3.1.1 Proof pressure test

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

The test pressure p_{test} shall be defined by the manufacturer and fulfill the following requirements:

- $p_{test} \geq 1.3$ (MAWP + 0.1 MPa)
- In case of metallic containers p_{test} shall be either at least equal to the maximum pressure of the inner container during fault management (as determined in B.5.2.3.3) or the manufacturer shall prove by calculation that at the maximum pressure of the inner container during fault management no yield occurs.
- For other materials than metallic p_{test} shall be at least equal to the maximum pressure of the inner container during fault management (as determined in B.5.2.3.3).

The test shall be done according to the following procedure:

a. The test shall be done on the inner storage container and the interconnecting pipes between inner storage container and vacuum jacket before the outer jacket is mounted.
b. The test shall be done either hydraulic with water or a glycol/water mixture or alternatively with gas. The container shall be pressurized to test pressure p_{test} in an even rate and kept at that pressure for at least 10 minutes.
c. The test shall be done at ambient temperature. In case of using gas to pressurize the container, the pressurization shall be done in a way that the container temperature stays at or around ambient temperature.

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

B.6.3.1.2 Baseline Initial Burst Pressure

The test shall be done according to the following procedure:

a. The test shall be done on the inner container at ambient temperature.
b. The test shall be done hydraulically with water or a water/glycol mixture.
c. The pressure shall be increased at a constant rate not exceeding 0.5 MPa/min until burst or leakage of the container occurs.

d. When the Maximum Allowable Working Pressure (MAWP) is reached there shall be a wait period of at least ten minutes at constant pressure so that the deformation of the tank shall be checked.
e. The pressure shall be recorded or written during the entire test.

For steel inner containers the test is passed when at least one of the two passing criteria described in chapter 5.2.1.2 is fulfilled. For inner containers made out of an aluminum alloy or other material a passing criterion shall be defined which guarantees at least the same level of safety compared to steel inner containers.

B.6.3.3 Verification for Expected On-road Performance

B.6.3.3.1 Boil-off test

The test shall be done according to the following procedure:

a. For pre-conditioning the container shall be fueled with liquid hydrogen to the specified maximum filling level. Subsequently hydrogen should be extracted until half filling level and the system should be allowed to completely cool down for at least 24 hours and maximum 48 hours.
b. The container shall be filled to the specified maximum filling level.
c. The container shall pressurize until boil-off pressure is reached.
d. The test shall last for at least another 48 hours after boil-off started and not terminated before the pressure stabilizes. Pressure stabilization has occurred when the average pressure does not increase over a two hour period.

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

- The pressure shall stabilize and stay below MAWP during the whole test.
- The pressure relief devices are not allowed to open during the whole test.

B.6.3.3.2 Leak test

The test shall be done according to the procedure described in B.6.1.1.2.

B.6.3.3.3 Vacuum loss test

The first part of the test shall be done according to the following procedure:

a. The vacuum loss test shall be conducted with a completely cooled-down container (according to the procedure in B.6.3.3.1).
b. The container shall be filled with liquid hydrogen to the specified maximum filling level.
c. The vacuum enclosure shall be flooded with air at an even rate to atmospheric pressure.
d. The test shall be terminated when the first pressure relief device does not open any more.

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

- The first pressure relief device shall open below or at MAWP and limit the pressure to not more than 110 per cent of the MAWP.
- The first pressure relief device shall not open at pressure above MAWP.
- The secondary pressure relief device shall not open during the entire test.

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

e. The vacuum shall be re-generated to a value specified by the manufacturer. The time for re-generation of the vacuum shall be at least 24 hours. The vacuum pump may stay connected until the time directly before the start of the vacuum loss.
f. The second part of the vacuum loss test shall be conducted with a completely cooled-down container (according to the procedure in B.5.2.3.1).
g. The container shall be filled to the specified maximum filling level.
h. The line downstream the first safety relieve device shall be blocked and the vacuum enclosure shall be flooded with air at an even rate to atmospheric pressure.
i. The test shall be terminated when the second pressure relief device does not open any more.

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

B.6.3.4 Verification Test for Service Terminating Performance of the LHSS Due to Fire

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

The first part of the test shall be done according to the following procedure:

a. The bonfire test shall be conducted with a completely cooled-down container (according to the procedure in B.6.3.3.1).
b. The tank shall have contained during the previous 24 hours a volume of liquid hydrogen at least equal to half of the water volume of the inner tank.
c. The tank shall be filled with liquid hydrogen so that the quantity of liquid hydrogen measured by the mass measurement system shall be half of the maximum allowed quantity that may be contained in the inner tank.
d. A fire shall burn 0.1 m underneath the tank. The length and the width of the fire shall exceed the plan dimensions of the container by 0.1 m. The temperature of the fire shall be at least 590 ºC. The fire shall continue to burn for the duration of the test.

e. The pressure of the tank at the beginning of the test shall be between 0 MPa and 0.01 MPa at the boiling point of hydrogen in the inner tank.
f. The test shall continue until at least one of the safety devices has opened and the subsequent venting has finished (when the PRD has reclosed or the internal pressure is less than half the lower operating pressure as defined by the manufacturer).As manufacturers may use PRDs which are not re-closing we should add an additional criterion that the test is also finished when the pressure is below a certain value, e.g. half the lower operating pressure as defined by the manufacturer. The latter is a comparable criterion to the CGH2 case where the test is finished as far as the pressure is below 1 MPa.
g. The test conditions and the maximum pressure reached within the tank during the test shall be recorded in a test certificate signed by the manufacturer and the technical service.

The test is passed when the following requirements are fulfilled:
a. The secondary pressure relief device shall not operate below 110 per cent of the set pressure of the primary pressure relief device.
b. The tank shall not burst and the pressure inside the inner tank shall not exceed the permissible fault range of the inner tank.

The permissible fault range for steel tanks is as follows:
- If a safety valve is used as secondary pressure relief device, the pressure inside the tank shall not exceed 136 per cent of the Maximum Allowable Working Pressure (MAWP) of the inner tank.
- If a burst disk is used outside the vacuum area as secondary pressure relief device, the pressure inside the tank shall be limited to 150 per cent of the Maximum Allowable Working Pressure (MAWP) of the inner tank.
- If a burst disk is used inside the vacuum area as secondary pressure relief device, the pressure inside the tank shall be limited to 150 per cent of the Maximum Allowable Working Pressure plus 0.1 MPa (MAWP + 0.1 MPa) of the inner tank.

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

B.6.4 TEST PROCEDURES FOR ELECTRIC SAFETY (B.5.4)
B.6.4.1 ISOLATION RESISTANCE MEASUREMENT METHOD

B.6.4.1.1 General
The isolation resistance for each high voltage bus of the vehicle shall be measured or shall be determined by calculation using measurement values from each part or component unit of a high voltage bus (hereinafter referred to as the "divided measurement").

B.6.4.1.2 Measurement Method
The isolation resistance measurement shall be conducted by selecting an appropriate measurement method from among those listed in Paragraphs B.6.4.1.2.1 through B.6.4.1.2.2, depending on the electrical charge of the live parts or the isolation resistance, etc.

The range of the electrical circuit to be measured shall be clarified in advance, using electrical circuit diagrams, etc.

Moreover, modification necessary for measuring the isolation resistance may be carried out, such as removal of the cover in order to reach the live parts, drawing of measurement lines, change in software, etc.

In cases where the measured values are not stable due to the operation of the on-board isolation resistance monitoring system, necessary modification for conducting the measurement may be carried out, such as stopping of the operation of the device concerned or removing it. Furthermore, when the device is removed, it must be proven, using drawings, etc., that it will not change the isolation resistance between the live parts and the electrical chassis.

Utmost care must be exercised as to short circuit, electric shock, etc., for this confirmation might require direct operations of the high-voltage circuit.

B.6.4.1.2.1 Measurement method using DC voltage from off-vehicle sources

B.6.4.1.2.1.1 Measurement instrument

An isolation resistance test instrument capable of applying a DC voltage higher than the working voltage of the high voltage bus shall be used.

B.6.4.1.2.1.2 Measurement method

An insulator resistance test instrument shall be connected between the live parts and the electrical chassis. Then, the isolation resistance shall be measured by applying a DC voltage at least half of the working voltage of the high voltage bus.
If the system has several voltage ranges (e.g. because of boost converter) in conductive connected circuit and some of the components cannot withstand the working voltage of the entire circuit, the isolation resistance between those components and the electrical chassis can be measured separately by applying their own working voltage with those component disconnected.

B.6.4.1.2.2 Measurement method using the vehicle's own RESS as DC voltage source

B.6.4.1.2.2.1 Test vehicle conditions

The high voltage-bus shall be energized by the vehicle's own RESS and/or energy conversion system and the voltage level of the RESS and/or energy conversion system throughout the test shall be at least the nominal operating voltage as specified by the vehicle manufacturer.

B.6.4.1.2.2.2 Measurement instrument

The voltmeter used in this test shall measure DC values and shall have an internal resistance of at least 10 MΩ.

B.6.4.1.2.2.3 Measurement method

B.6.4.1.2.2.3.1 First step

The voltage is measured as shown in Figure 1 and the high voltage Bus voltage (V_b) is recorded. V_b shall be equal to or greater than the nominal operating voltage of the RESS and/or energy conversion system as specified by the vehicle manufacturer.

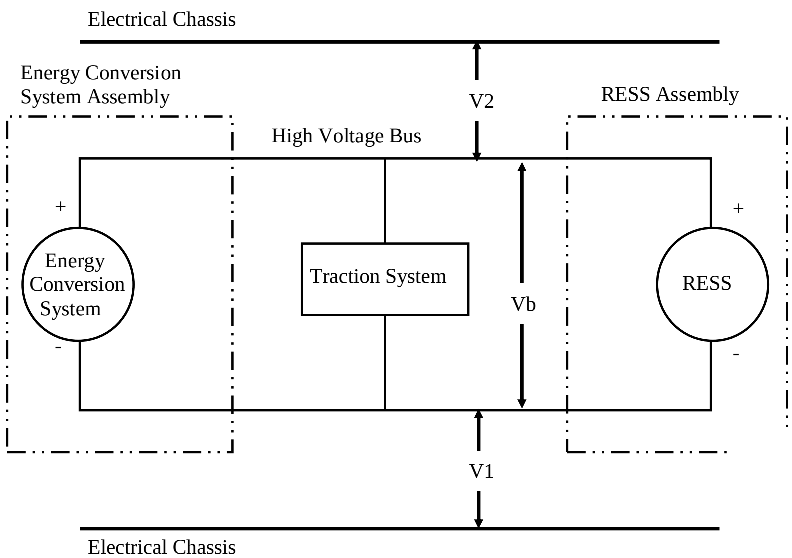


Figure 1: Measurement of Vb, V1, V2

B.6.4.1.2.2.3.2 Second step

Measure and record the voltage (V1) between the negative side of the high voltage bus and the electrical chassis (see Figure 1):

B.6.4.1.2.2.3.3 Third step

Measure and record the voltage (V2) between the positive side of the high voltage bus and the electrical chassis (see Figure 1):

B.6.4.1.2.2.3.4 Fourth step

If V1 is greater than or equal to V2, insert a standard known resistance (Ro) between the negative side of the high voltage bus and the electrical chassis. With Ro installed, measure the voltage (V1') between the negative side of the high voltage bus and the electrical chassis (see Figure 2).

Calculate the electrical isolation (Ri) according to the following formula:

$$Ri = Ro*(Vb/V1' - Vb/V1) \quad \text{or} \quad Ri = Ro*Vb*(1/V1' - 1/V1)$$

Divide the result Ri, which is the electrical isolation resistance value (in Ω), by the working voltage of the high voltage bus in volt (V).

$$Ri\ \Omega / V = Ri\ \Omega / \text{Working voltage (V)}$$

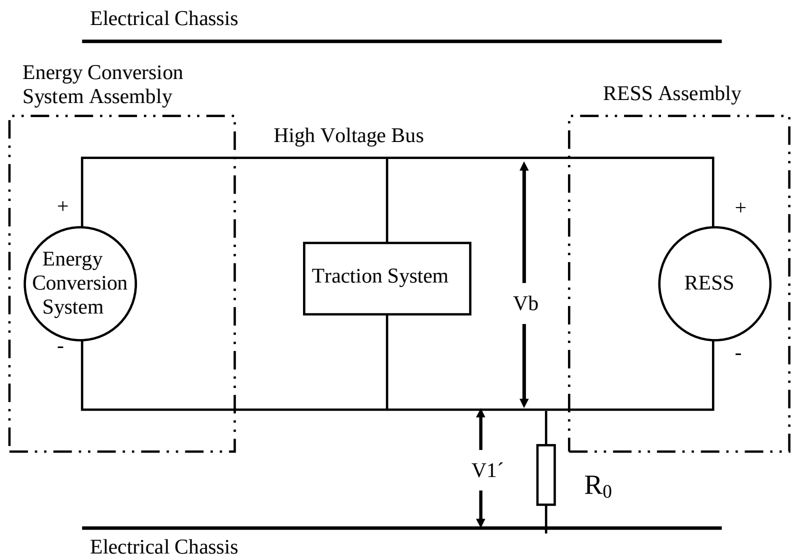


Figure 2: Measurement of V1´

If V2 is greater than V1, insert a standard known resistance (Ro) between the positive side of the high voltage bus and the electrical chassis. With Ro installed, measure the voltage (V2') between the positive side of the high voltage bus and the electrical chassis. (See Figure 3).Calculate the electrical isolation (Ri) according to the formula shown. Divide this electrical isolation value (in ohms) by the nominal operating voltage of the high voltage bus (in volts).

Calculate the electrical isolation (Ri) according to the following formula:

Ri = Ro*(Vb/V2' – Vb/V2)   or   Ri = Ro*Vb*(1/V2' – 1/V2)

Divide the result Ri, which is the electrical isolation resistance value (in Ω), by the working voltage of the high voltage bus in volt (V).

Ri Ω / V = Ri Ω / Working voltage V

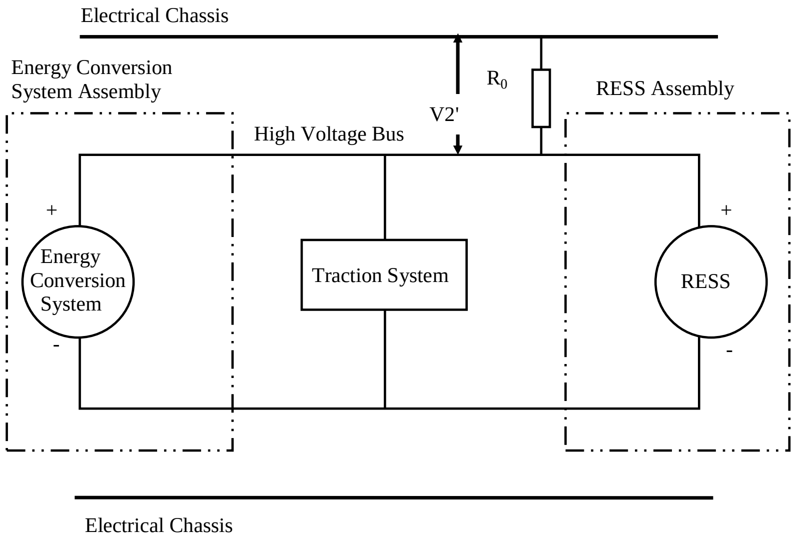


Figure 3: Measurement of V2'

B.6.4.1.2.2.3.5 Fifth step

The electrical isolation value Ri (in ohms) divided by the working voltage of the high voltage bus (in volts) results in the isolation resistance (in ohms/volt).

(NOTE 1: The standard known resistance Ro (in ohms) should be the value of the minimum required isolation resistance (in ohms/V) multiplied by the working voltage of the vehicle plus/minus 20% (in volts). Ro is not required to be precisely this value since the equations are valid for any Ro; however, a Ro value in this range should provide good resolution for the voltage measurements.)

B.6.4.2 Confirmation Method for Functions of On-board Isolation Resistance Monitoring System

The function of the on-board isolation resistance monitoring system shall be confirmed by the following method or a method equivalent to it.

Insert a resistor that does not cause the isolation resistance between the terminal being monitored and the electrical chassis to drop below the minimum required isolation resistance value. The warning shall be activated.

B.6.4.3 PROTECTION AGAINST DIRECT CONTACTS OF PARTS UNDER VOLTAGE

B.6.4.3 1 Access probes

Access probes to verify the protection of persons against access to live parts are given in table 1.

B.6.4.3 .2 Test conditions

The access probe is pushed against any openings of the enclosure with the force specified in table 1. If it partly or fully penetrates, it is placed in every possible position, but in no case shall the stop face fully penetrate through the opening.

Internal electrical protection barriers are considered part of the enclosure.

A low-voltage supply (of not less than 40 V and not more than 50 V) in series with a suitable lamp should be connected, if necessary, between the probe and live parts inside the electrical protection barrier or enclosure.

The signal-circuit method should also be applied to the moving live parts of high voltage equipment.
Internal moving parts may be operated slowly, where this is possible.

B.6.4.3 .3 Acceptance conditions

The access probe shall not touch live parts.
If this requirement is verified by a signal circuit between the probe and live parts, the lamp shall not light.
In the case of the test for IPXXB, the jointed test finger may penetrate to its 80 mm length, but the stop face (diameter 50 mm x 20 mm) shall not pass through the opening. Starting from the straight position, both joints of the test finger shall be successively bent through an angle of up to 90 degree with respect to the axis of the adjoining section of the finger and shall be placed in every possible position.
In case of the tests for IPXXD, the access probe may penetrate to its full length, but the stop face shall not fully penetrate through the opening.

Table 1 - Access probes for the tests for protection of persons against access to hazardous parts

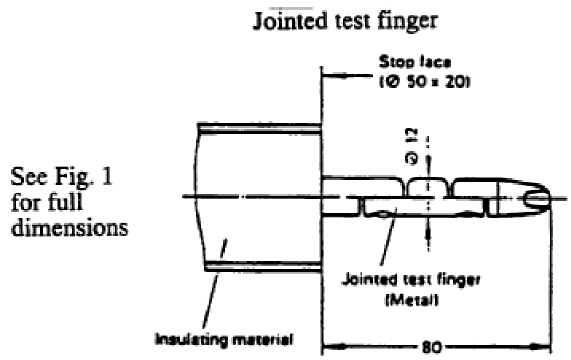
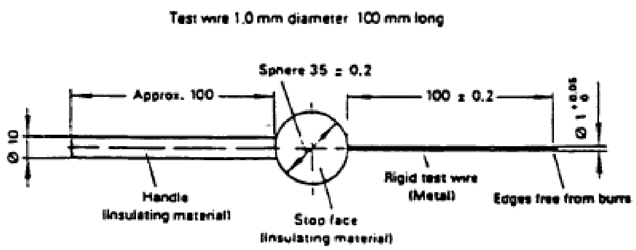
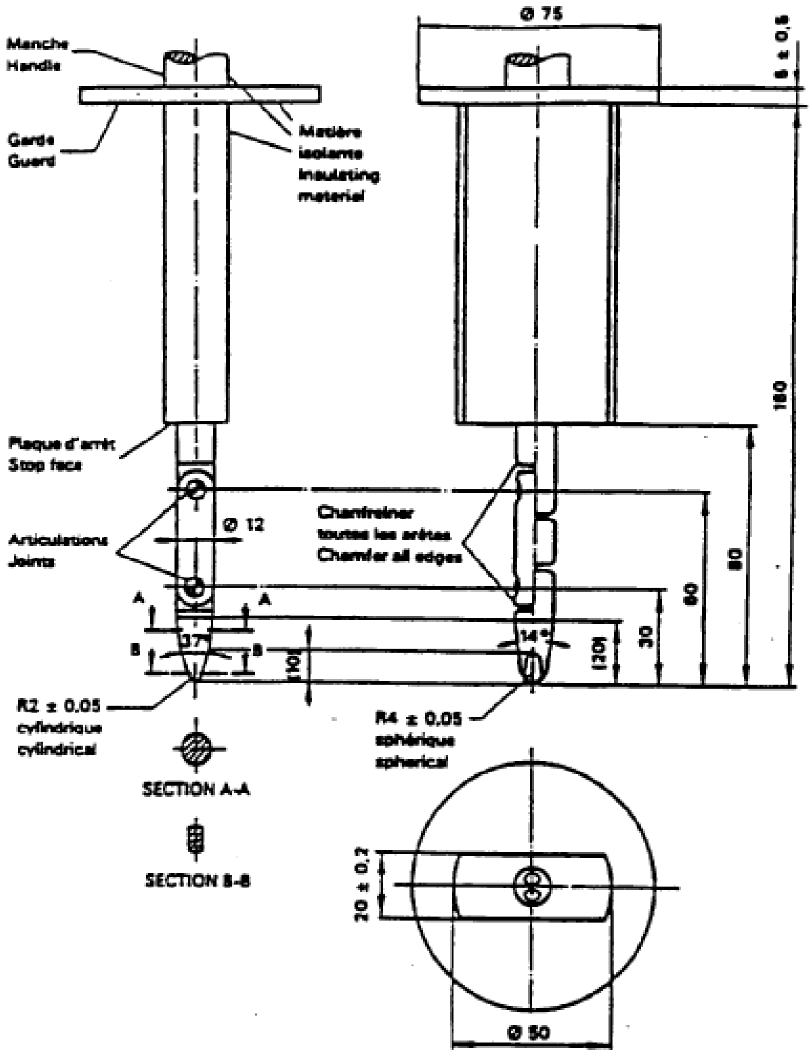
First numeral	Addit. letter	Access probe	Test force
2	B		10N+/-10%
4.5.6	D		1N+/-10%

Figure 1 - Jointed test finger



Material: metal. except where otherwise specified
Linear dimensions in millimeters
Tolerances on dimensions without specific tolerance:
on angles, 0/-10'
on linear dimensions:
up to 25 mm: 0/-0.05
over 25 mm:+/- 0.2
Both joints shall permit movement in the same plane and the same direction through an angle of 90^0 with a 0 to $+10^0$ tolerance.

B.6.4.4 TEST METHOD FOR MEASURING ELECTRIC RESISTANCE

A) Test method using a resistance tester

Connect the resistance tester to the measuring points (Typically, electrical chassis and electro conductive enclosure/electrical protection barrier) and measure the resistance using a resistance tester that meets the specification that follows.

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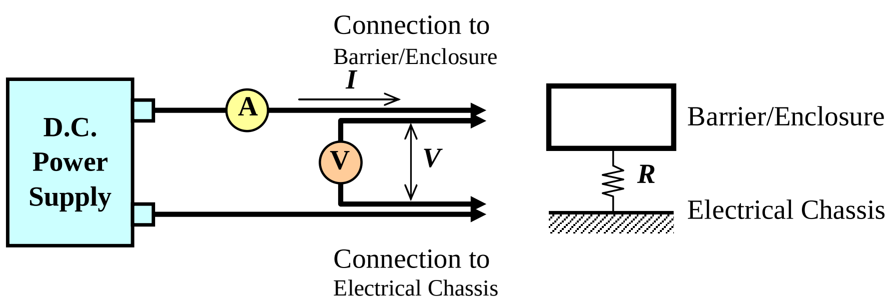
Resistance tester:	Measurement current at least 0.2 A
	Resolution 0.01 Ω or less

The resistance ***R*** shall be less than 0.1 ohm.

B) Test method using D.C. power supply, voltmeter and ammeter.

Example of the test method using D.C. power supply, voltmeter and ammeter is shown below.

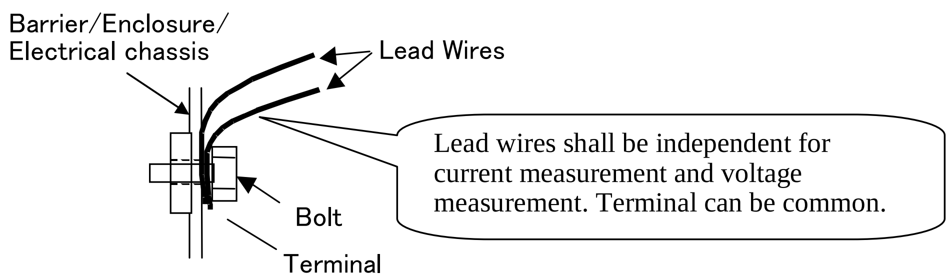


Test Procedure

- Connect the D.C. power supply, voltmeter and ammeter to the measuring points (Typically, electrical chassis and electro conductive enclosure/electrical protection barrier).
- Adjust the voltage of the D.C. power supply so that the current flow becomes more than 0.2 A.
- Measure the current "***I***" and the voltage "***V***".
- Calculate the resistance "***R***" according to the following formula:
  $R = V / I$

The resistance ***R*** shall be less than 0.1 ohm.

Note: In case lead wires are used for voltage and current measurement, each lead wire shall be independently connected to the electrical protection barrier/enclosure/electrical chassis. Terminal can be common for voltage measurement and current measurement.



B.6.4.5 TEST CONDITIONS AND TEST PROCEDURE REGRADING POST CRASH

B.6.4.5.1 Test Conditions

B.6.4.5 .1.1 General

The test conditions specified in paragraphs B.6.4.5 .1.2 through B.6.4.5.1.4 shall be used.

Where a range is specified, the vehicle shall be capable of meeting the requirements at all points within the range.

B.6.4.5 .1.2 Electrical power train adjustment

B.6.4.5 .1.2.1 The RESS shall be at any state of charge, which allows the normal operation of the power train as recommended by the manufacturer.

B.6.4.5. 1.2.2 The electrical power train shall be energized with or without the operation of the original electrical energy sources (e.g. engine-generator, RESS or electric energy conversion system), however:

B.6.4.5 .1.2.2.1 it shall be permissible to perform the test with all or parts of the electrical power train not being energized insofar as there is no negative influence on the test result. For parts of the electrical power train not energized, the protection against electrical shock shall be proved by either physical protection or isolation resistance and appropriate additional evidence.

B.6.4.5 .1.2.2.2 in the case where the power train is not energized and an automatic disconnect is provided, it shall be permissible to perform the test with the automatic disconnect being triggered. In this case it shall be demonstrated that the automatic disconnect would have operated during the impact test. This includes the automatic activation signal as well as the conductive separation considering the conditions as seen during the impact.

[**B.6.4.5. 1.3** It shall be allowed to modify the fuel system so that an appropriate amount of fuel can be used to run the engine or the electrical energy conversion system.]

B.6.4.5 .1.4 The vehicle conditions other than specified in paragraphs B.6.4.5 .1.1 through B.6.4.5.1.3 shall be in the crash test protocols of the contracting parties.

B.6.4.5.2 Test Procedures for the protection of the occupants of vehicles operating on electrical power from high voltage and electrolyte spillage

This section describes test procedures to demonstrate compliance to the electrical safety requirements of B.5.4.2.

Before the vehicle impact test conducted, the high voltage bus voltage (Vb) (see figure 1) shall be measured and recorded to confirm that it is within the operating voltage of the vehicle as specified by the vehicle manufacturer.

B.6.4.5 .2.1 Test setup and equipment

If a high voltage disconnect function is used, measurements are to be taken from both sides of the device performing the disconnect function.

However, if the high voltage disconnect is integral to the RESS or the energy conversion system and the high-voltage bus of the RESS or the energy conversion system is protected according to protection IPXXB following the impact test, measurements may only be taken between the device performing the disconnect function and electrical loads.

The voltmeter used in this test shall measure DC values and have an internal resistance of at least 10 MΩ.

B.6.4.5.2.2 The following instructions may be used if voltage is measured.

After the impact test, determine the high voltage bus voltages (Vb, V1, V2) (see figure 1).
The voltage measurement shall be made not earlier than 5 seconds, but not later than 60 seconds after the impact.

This procedure is not applicable if the test is performed under the condition where the electric power train is not energized.

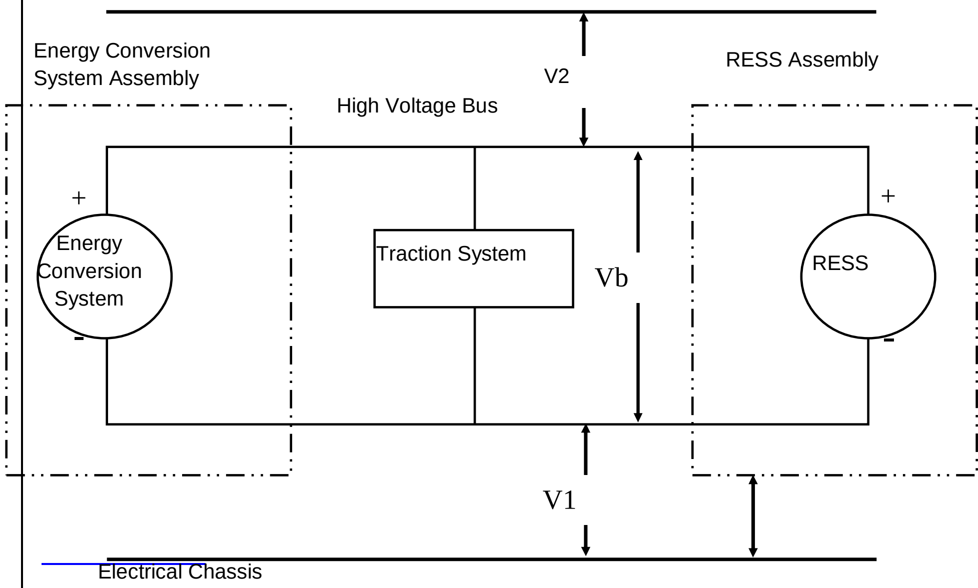


Figure 1 Measurement of Vb, V1, V2

B.6.4.5 .2.3 Isolation resistance

See B.6.4.1.2 “Measurement method”

All measurements for calculating voltage(s) and electrical isolation are made after a minimum of 5 seconds after the impact.

For example, megohmmeter or oscilloscope measurements are an appropriate alternative to the procedure described above for measuring isolation resistance. In this case it may be necessary to deactivate the on-board isolation resistance monitoring system.

[B.6.4.5 .2.4 Physical Protection

Following the vehicle impact test any parts surrounding the high voltage components shall be, without the use of tools, opened, disassembled or removed. All remaining surrounding parts shall be considered part of the physical protection.

The Jointed Test Finger described in B.6.4.3 shall be inserted into any gaps or openings of the physical protection with a test force of 10 N ± 10 per cent for electrical safety assessment. If partial or full penetration into the physical protection by the Jointed Test Finger occurs, the Jointed Test Finger shall be placed in every position as specified below.

Starting from the straight position, both joints of the test finger shall be rotated progressively through an angle of up to 90 degrees with respect to the axis of the adjoining section of the finger and shall be placed in every possible position.

Internal electrical protection barriers are considered part of the enclosure

If appropriate a low-voltage supply (of not less than 40 V and not more than 50 V) in series with a suitable lamp should be connected, between the Jointed Test Finger and high voltage live parts inside the electrical protection barrier or enclosure

B.6.4.5 .2.4.1 Acceptance conditions

The requirements of paragraph B.5.4.2.2.3s hall be considered to be met if the Jointed Test Finger described in B.6.4.3 is unable to contact high voltage live parts.

If necessary a mirror or a fiberscope may be used in order to inspect whether the Jointed Test Finger touches the high voltage buses.

If this requirement is verified by a signal circuit between the Jointed Test Finger and high voltage live parts, the lamp shall not light.]

B.6.4.5 .2.5 Low electrical Energy

Prior to the impact a switch S1 and a known discharge resistor Re is connected in parallel to the relevant capacitance (ref. figure 2).

Not earlier than 5 seconds and not later than 60 seconds after the impact the switch S1 shall be closed while the voltage Vb and the current Ie are measured and recorded.

The product of the voltage Vb and the current Ie shall be integrated over the period of time, starting from the moment when the switch S1 is closed (t_c) until the voltage Vb falls below the high voltage threshold of 60 V DC (t_h). The resulting integration equals the total energy (TE) in joules.

(a) $$TE = \int_{tc}^{th} V_b \times I_e \, dt$$

When Vb is measured at a point in time between 5 seconds and 60 seconds after the impact and the capacitance of the X-capacitors (C_x) is specified by the manufacturer or determined by measurement total energy (TE) shall be calculated according to the following formula:

(b) $$TE = 0.5 \times C_x \times (V_b^2 - 3\,600)$$

When V1, V2 (see figure 1) are measured at a point in time between 5 seconds and 60 seconds after the impact and the capacitances of the Y-capacitors (C_{y1}, C_{y2}) are specified by the manufacturer or determined by measurement total energy (TE_{y1}, TE_{y2}) shall be calculated according to the following formulas:

(c) $$TE_{y1} = 0.5 \times C_{y1} \times (V_1^2 - 3\,600)$$

$$TE_{y2} = 0.5 \times C_{y2} \times (V_2^2 - 3\,600)$$

This procedure is not applicable if the test is performed under the condition where the electric power train is not energized.

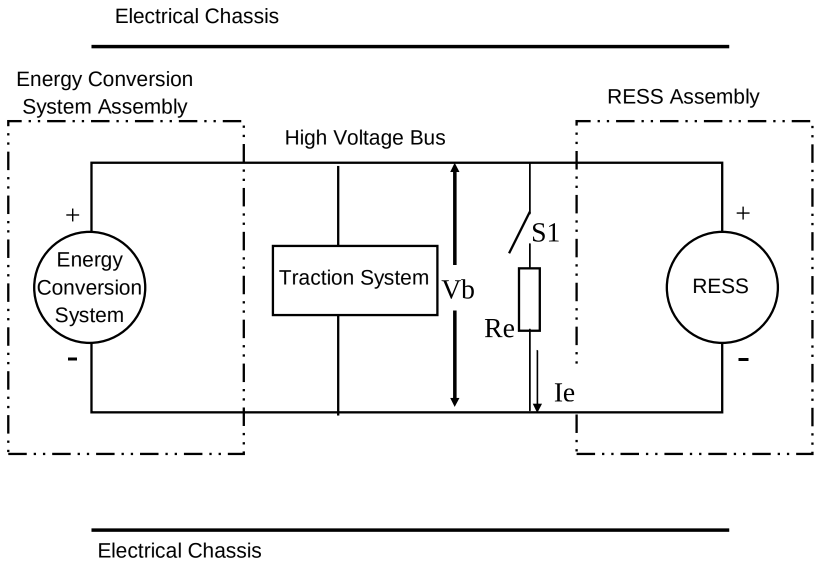


Figure 2: E.g. measurement of high voltage bus energy stored in X-capacitors

B.6.4.5 .2.6 Electrolyte spillage

Appropriate coating shall be applied, if necessary, to the physical protection in order to confirm any electrolyte leakage from the RESS after the impact test.

Unless the manufacturer provides means to differentiate between the leakage of different liquids, all liquid leakage shall be considered as the electrolyte.

B.6.4.5 .2.7 RESS retention

Compliance shall be determined by visual inspection

B.7. ANNEX: Requirements applicable for Contracting Parties with Type Approval Systems

B.7.1 Type Approval Requirements for Compressed Hydrogen Storage

B.7.1.1 Material Test Requirements

Manufacturers shall maintain records of testing that confirm compliance of materials used in the hydrogen storage system with requirements of B.6.2.1. The manufacturer shall provide that information to regulatory authorities upon request.

Constraints on minimum BP_{min} derived in the Material Qualification (B.6.2.1.3) shall be applied as requirements for the minimum BP_{min} in B.5.1.1.1 (Baseline Initial Burst Pressure) and in B.7.1.3.ii(a) (Verification Test for Conformity of Production).

B.7.1.2 Verification Tests for Consistency of the Qualification Batch

If #Cycles (established in B.5.1.1.2) is less than 11000, then the pressure cycle life, PCL, (number of cycles until leak) of each container tested in B.5.1.1.2 shall be recorded. The manufacturer will supply documentation to establish the midpoint pressure cycle life of new storage containers, PCL_O. If PCL_O is less than 11,000, or if the PCL any of the three containers tested is less than 11,000 and not within $\pm$25% of PCL_O, then three (3) containers will be required to undergo the testing in B.5.1.2, the Durability Performance (Hydraulic) Tests. If the PCL of each container greater than 11,000 or is within $\pm$ 25% of PCL_O, then one (1) containerl will be required to undergo testing according to B.5.1.2.

B.7.1.3 Verification Tests for Conformity of Production

Manufacturers shall maintain records pertaining to the conformity of production units with production protypes presented for design qualification in B.5.1.2. Manufacturing reccords should document the selection and range of manufacturing control variables, batch size, and the content and frequency of unit and batch testing to establish confidence that all production units have the capability to meet the requirements of design qualification testing in B.5.1.2, B.7.1.1 and B.7.1.4, and be in compliance with ISO 9000 standards for manufacturing quality control. Manufacturers of storage systems shall maintain and following information and provide it to regulatory authorities upon request.

i. Documentation of Routine Production (Each Produced Unit). Documentation shall 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 shall show that components providing closure functions, such as the shut-off valve, check valve and the TPRD are qualified to B.7.1.4.

ii. Documentation of Periodic Production Tests (Batch/Lot Tests). Periodic (batch) testing shall be designed according to the manufacturer's documented quality control protocol. Documentation (measurements and statistical analyses) shall establish the frequency of batch testing needed to assure that the burst pressure of every unit is greater than or equal to a minimum burst pressure BP_{min} of 200% NWP (or greater if required by B.6.2.1.3), and greater than 90% BPo (BP_O is established in B.5.1.1.1.). The frequency of batch testing shall also assure that the pressure cycle life of every unit is greater than #Cycles. The default periodic (batch) sampling frequency in the absence of statistical documentation is once in every 200 production units; after ten successful batch tests, the default periodic frequency (batch size) may be increased up to 2000.

Periodic (batch) testing shall include material tests in B.6.2.1.1 (Material Tests for Conformity of Production) and at least one container shall undergo (a) burst pressure testing and (b) pressure cycle testing. The same container may be used for both the pressure cycle and burst tests. If a container fails to meet the burst pressure requirement or the pressure cycle requirement, then all production since the previous successful periodic/batch test shall be rejected (not qualified for use in vehicle service).

(a) Burst pressure test to confirm the burst pressure is greater than or equal to 200% NWP (or greater if required by B.6.2.1.3) and greater than or equal to 90% BP_O. Appropriate multi-batch statistics shall be used to monitor trends in the overall burst pressure midpoint, and appropriate corrective action will be undertaken as needed to maintain the midpoint burst pressure of units at greater than or equal to BP_0.

(b) Pressure cycle test to confirm absence of leak and rupture within #Cycles. Subsequently, on the same container, conduct proof pressure test to 180% NWP for at least 30 seconds to establish additional resistance to rupture under static stress. If #Cycles is less than 11,000, appropriate multi-batch statistics of batch pressure cycle life measurements shall be used to monitor trends in the overall pressure cycle life, and appropriate corrective action will be undertaken as needed to maintain the midpoint pressure cycle life of units at greater than or equal to PCL_0

B.7.1.4 Qualification of Hydrogen-Flow Closures. Manufacturers shall maintain records that confirm that closures that isolate the high pressure hydrogen storage system (the TPRD(s), check valve(s) and shut-off valve(s) shown in Figure B.5.1.1) meet the requirements described in the remainder of this Section.

The entire storage system does not have to be re-qualified (B.5.1) if these closure components (components in Figure B.5.1.1 excluding the storage container) are exchanged for equivalent closure components having comparable function, fittings, materials, strength and dimensions, and qualified for performance using the same qualification tests as the original components. However, a change in TPRD hardware, its position of installation or venting lines requires re-qualification with fire testing according to B.5.1.4.

B.7.1.4.1 TPRD Qualification Requirements

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

- Pressure Cycling Test (B.8.1.1 test procedure)
- Accelerated Life Test (B.8.1.2 test procedure)
- Temperature Cycling Test (B.8.1.3 test procedure)
- Salt Corrosion Resistance Test (B.8.1.4 test procedure)
- Stress Corrosion Test (B.8.1.5 test procedure)
- Drop and Vibration Test (B.8.1.6 test procedure)
- Leak Test (B.8.1.7 test procedure)
- Bench Top Activation Test (B.8.1.8 test procedure)
- Flow Rate Test (B.8.1.9 test procedure)

B.7.1.4.2 Check Valve and Automatic Shut-Off Valve Qualification Requirements

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

- Hydrostatic Strength Test (B.8.2.1)
- Leak Test (B.8.2.2)
- Extreme Temperature Pressure Cycling Test (B.8.2.3)
- Salt Corrosion Test (B.8.2.4)
- Vehicle Environment Test (B.8.2.5)
- Atmospheric Exposure Test (B.8.2.6)
- Electrical Tests (B.8.2.7)
- Vibration Test (B.8.2.8)
- Stress Corrosion Test (B.8.2.9)
- Pre-Cooled Hydrogen Exposure Test (B.8.2.10)

B.7.2 Type Approval Requirements for Liquefied Hydrogen Storage

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

The test shall at least include:

- Pressure cycling with a number of cycles at least three times the number of possible full pressure cycles (from the lowest to highest operating pressure) for an expected on-road performance. Pressure cycling should be conducted between atmospheric pressure and MAWP at liquid nitrogen temperatures, e.g. by filling the container to with liquid nitrogen to certain level and alternately pressurizing and depressurizing it with (pre-cooled) gaseous nitrogen or helium.

7.2.2 In the case that non-metallic materials are used for the container(s) and/or vacuum jacket(s) in addition to the mandatory tests described in chapter B.5.2 suitable tests have to be accomplished, which prove the same level of safety compared to a metallic container design supported by calculation according to accepted standards as described in 7.2.1.

SGS-10 >> indentify critical components for LHSS type approval. These will be part of the Annex~~.~~

B.7.3 TYPE APPROVAL REQUIREMENTS FOR FUEL SYSTEM INTEGRITY

B.7.3.1 Overpressure protection for the low pressure system.
The hydrogen system downstream of a pressure regulator shall be protected against overpressure due to the possible failure of the pressure regulator. The set pressure of the overpressure protection device shall be lower than or equal to the maximum allowable working pressure for the appropriate section of the hydrogen system.

B.7.3.2 Fueling receptacle requirements:

B.7.3.2.1 The fuelling receptacle should be properly secured to the vehicle, protected against maladjustment and rotation, (e.g. accomplished by means of positive locking in all directions), and installed in such a manner that it provides safety against reasonably foreseeable handling errors. The receptacle should also be protected from unauthorized interference, and the ingress of dirt and water as far as is reasonably practicable, (e.g. should be installed in a compartment which can be locked).

B.7.3.2.2 The fuelling receptacle shall not be mounted within the external energy absorbing elements of the vehicle (e.g. bumper) and shall not be installed in the passenger compartment, luggage compartment and other places where hydrogen gas could accumulate and where ventilation is not sufficient.

B.7.3.3.3 In vehicles with Liquid Hydrogen Storage Systems, flammable materials used in the vehicle shall be protected from liquefied air that may condense on elements of the fuel system.

B.7.4 TYPE APPROVAL REQUIREMENTS FOR RECHARGEABLE ENERGYSTORAGE SYSTEM REQUIREMENTS (RESS)

B.7.4.1Protection against excessive current
The RESS shall not overheat.

If the RESS is subject to overheating due to excessive current, it shall be equipped with a protective device such as fuses, circuit breakers or main contactors.

However, the requirement may not apply if the manufacturer supplies data that ensures overheating from excessive current is prevented without the protective device.

~~**B.5.4.1.3.2 Accumulation of Gas**~~
~~Places for containing open type traction battery that may produce hydrogen gas shall be provided with a ventilation fan or a ventilation duct to prevent the accumulation of hydrogen gas.~~

B.8 ANNEX: TYPE APPROVAL TEST PROCEDURES FOR CLOSURES IN COMPRESSED HYDROGEN STORAGE SYSTEM

B.8.1 TYPE APPROVAL TPRD Qualification Performance Tests

Testing shall be performed with hydrogen gas having gas quality compliant with ISO 14687-2/SAE J2719. All tests shall be performed at ambient temperature 20(+5)°C unless otherwise specified. The HPRD qualification performance tests are specified as follows:

B.8.1.1 Pressure Cycling Test

Five TPRD units shall undergo 11,000 internal pressure cycles with hydrogen gas having gas quality compliant with ISO 14687-2/SAE J2719. The first five pressure cycles shall be between < 2MPa and 150% NWP; the remaining cycles shall be between 2(+1)MPa and 125% NWP(+1MPa). The first 1500 pressure cycles shall be conducted at a TPRD temperature of +85(+5)°C. The remaining cycles shall be conducted at a TPRD temperature of +55(+5)°C. The maximum pressure cycling rate is ten cycles per minute. Following this test, the pressure relief device shall meet the requirements of the Leak Test (B.8.1.8) and the Bench Top Activation Test (B.8.1.9).

B.8.1.2 Accelerated Life Test

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

B.8.1.3 Temperature Cycling Test

(1) Place an unpressurized TPRD in a liquid bath maintained at -35(±5)°C at least two hours. Transfer the TPRD to a liquid bath maintained at +85(±5)°C within five minutes, and maintain that temperature at least two hours. Transfer the TPRD to a liquid bath maintained at -35(±5)°C within five minutes.
(2) Repeat step (a) until 15 thermal cycles have been achieved.
(3) With the TPRD conditioned for a minimum of two hours in the -35°C liquid bath, cycle the internal pressure of the TPRD with hydrogen gas between < 2MPa and 100%NWP for 100 cycles while maintaining the liquid bath at -35(±5)°C.
(4) Following the thermal and pressure cycling, the TPRD shall meet the requirements of the Leak Test (B.8.1.8), except that the test shall be conducted at -35(±5)°C, and the Bench Top Activation Test (B.8.1.9).

B.8.1.4 Salt Corrosion Test

Two TPRD units shall be tested. Any non-permanent outlet caps shall be removed. Each TPRD unit shall be installed in a test fixture in accordance with the manufacturer's recommended procedure so that external exposure is consistent with realistic installation. Each unit shall be pressurized to 125 percent of the service pressure and exposed for 144 hours to a salt spray (fog) test as specified in ASTM B117 (Standard Practice for Operating Salt Spray (Fog) Apparatus) except that in the test of one unit, the pH of the salt solution shall be adjusted to 4.0 ± 0.2 by the addition of sulfuric acid and nitric acid in a 2:1 ratio, and in the test of the other unit, the pH of the salt solution shall be adjusted to 10.0 ± 0.2 by the addition of sodium hydroxide. Following these tests, each pressure relief device shall meet the requirements of the Leak Test (B.8.1.8) and the Bench Top Activation Test (B.8.1.9).

B.8.1.5 Corrosion Test.

For TPRDs containing components made of a copper-based alloy (e.g., brass), one TPRD unit shall be tested. The TPRD shall be disassembled, all copper alloy components shall be degreased and then the TPRD shall be reassembled before it is continuously exposed for ten days to a moist ammonia-air mixture maintained in a glass chamber having a glass cover. Aqueous ammonia having a specific gravity of 0.94 shall be maintained at the bottom of the glass chamber below the sample at a concentration of at least 20 ml per liter of chamber volume. The sample shall be positioned 35(±5) mm above the aqueous ammonia solution and supported in an inert tray. The moist ammonia-air mixture shall be maintained at atmospheric pressure at +35(±5)ºC. Brass units shall not exhibit cracking or delamination due to this test.

B.8.1.6 Drop and Vibration Test

(1) Six TPRD units shall be dropped from a height of 2 m at ambient temperature onto a smooth concrete surface. Each sample shall be allowed to bounce on the concrete surface after the initial impact. One unit shall be dropped in six orientations (opposing directions of 3 orthogonal axes). If each of the six dropped samples do not show visible exterior damage that indicates that the part is unsuitable for use, then it shall proceed to step (b).
(2) Each of the six TPRD units dropped in step (a) and one additional unit not subjected to a drop shall be mounted in a test fixture in accordance with manufacturer's installation instructions and vibrated 30 minutes along each of the three orthogonal axes at the most severe resonant frequency for each axis. The most severe resonant frequencies shall be

determined using an acceleration of 1.5 g and sweeping through a sinusoidal frequency range of 10 to 500Hz within 10 minutes. The resonance frequency is identified by a pronounced increase in vibrational amplitude. If the resonance frequency is not found in this range, the test shall be conducted at 500 Hz. Following this test, each sample shall not show visible exterior damage that indicates that the part is unsuitable for use. Then it shall meet the requirements of the Leak Test (B.8.1.8) and the Bench Top Activation Test (B.8.1.9).

B.8.1.7 Leak Test

The TPRD unit shall be held at 125% NWP with hydrogen gas for one hour at ambient temperature before leakage is measured. The method for measuring is at the discretion of the testing facility; the accuracy, response time and calibration of the measurement method shall be documented. The total hydrogen leak rate shall be less than 0.2 Ncc/hr.

B.8.1.8 Bench Top Activation Test

Two new TPRD units shall be tested without being subjected to other design qualification tests in order to establish a baseline time or pressure for activation.

(1) The test setup shall consist of either an oven or chimney which is capable of controlling air temperature and flow to achieve +600(± 10)°C in the air surrounding the TPRD. The TPRD unit shall not be exposed directly to flame. The TPRD unit shall be mounted in a fixture that shall be documented.

(2) Place a thermocouple in the oven or chimney to monitor the temperature. The temperature shall remain within the acceptable range for two minutes prior to running the test.

(3) Insert the pressurized TPRD unit into the oven or chimney, and record the time for the device to activate. Prior to insertion into the oven or chimney, pressurize one new TPRD unit to no more than 25% NWP; pressurize the pre-tested (B.8.1.2.1.a, c, d, e or g) TPRD units to no more than 25% NWP; and pressurize one new TPRD unit to 100% NWP.

(4) TPRD units previously subjected to testing in B.8.1.1, B.8.1.3, B.8.1.4, B.8.1.5 or B.8.1.7 shall activate within a period no more than two minutes longer than the baseline activation time of the new TPRD unit that was pressurized to up to 25% NWP.

(5) The difference in the activation time of the two TPRD units that had not undergone previous testing shall be no more than 2 minutes.

B.8.1.9 Flow Rate Test

(1) Nine TPRD units shall be tested for flow capacity. The nine units shall consist of one unit from those previously tested in each of B.8.1.1, B.8.1.3, B.8.1.4, B.8.1.6 or B.8.1.7, and three new TPRD units.

(2) Each TPRD unit be activated according to B.8.1.9. After activation and without cleaning, removing parts, or reconditioning, each TPRD unit shall be subjected to flow test using hydrogen, air or an inert gas.

(3) Flow rate testing shall be conducted with a gas inlet pressure of 2(±0.5) MPa. The outlet shall be ambient pressure. The inlet temperature and pressure shall be recorded.

(4) Flow rate shall be measured with accuracy within ±2 percent. The lowest measured value of the nine pressure relief devices shall not be less than 90 percent of the highest flow value.

(5) Flow rate shall be recorded as the lowest measured value of the nine pressure relief devices tested in NL per minute (0^oC and 1 atmosphere) corrected for hydrogen.

B.8.2 TYPE APPROVAL Qualification Performance Tests for Check Valve and Shut-Off Valve

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

B.8.2.1 Hydrostatic Strength Test

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

(1) A hydrostatic pressure of 250% NWP shall be applied to the inlet of the component for three minutes. The component shall be examined to ensure that rupture has not occurred.

(2) The hydrostatic pressure shall then be increased at a rate of less than or equal to 1.4 MPa/sec until component failure. The hydrostatic pressure at failure shall be recorded. The failure pressure of previously tested units shall be no less than 80 percent of the failure pressure of the baseline, unless the hydrostatic pressure exceeds 400% NWP.

B.8.2.2 Leak Test

One unit shall be tested at ambient temperature without being subjected to other design qualification tests. Three temperature regimes are specified:

(1) Ambient temperature: condition the unit at $20(\pm 5)^oC$; test at 5% NWP and 150%

(2) High temperature: condition the unit at $+85(\pm 5)^oC$; test at 5% NWP and 150%

(3) Low temperature: condition the unit at $-40(\pm 5)^oC$; test at 5% NWP and 100%NWP.

Additional units shall undergo leak testing as specified in subsequent tests (B.8.2.3, B.8.2.4, B.8.2.5, B.8.2.8, B.8.2.11 and B.8.2.12) with uninterrupted exposure to the temperatures specified in those tests.

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

B.8.2.3 Extreme Temperature Continuous Valve Cycling Test

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

An operational cycle shall be defined as follows:

(a) For a check valve, connect the check valve to a test fixture and apply pressure in six pulses to the check valve inlet with the outlet closed. Then vent pressure from the check valve inlet. Lower the pressure on the check valve outlet side to < 60% NWP prior to the next cycle.

(b) For an automatic shut-off valve, connect the shut-off valve to a test fixture and apply pressure continuously to the both the inlet and outlet sides.

An operational cycle shall consist of one full operation and reset within an appropriate period as determined by the testing agency.

(2) Testing shall be performed on a unit stabilized at the following temperatures:

(a) Ambient Temperature Cycling. The unit shall be undergo operational (open/closed) cycles at 125% NWP through 90 percent of the total cycles with the part stabilized at 20 ($\pm$5)^{o}C. At the completion of the ambient temperature operational cycles, the unit shall comply with the ambient temperature leakage test specified in B.8.2.2.

(b) High Temperature Cycling. The unit shall then undergo operational cycles at 125% NWP through 5 percent of the total operational cycles with the part stabilized at +85($\pm$5)^{o}C. At the completion of the +85^{o}C cycles, the unit shall comply with the high temperature (+85^{o}C) leakage test specified in B.8.2.2.

(c) Low Temperature Cycling. The unit shall then undergo operational cycles at 100% NWP through 5 percent of the total cycles with the part stabilized at -40^{o}C. At the completion of the -40^{o}C operational cycles, the unit shall comply with the low temperature (-40^{o}C) leakage test specified in B.8.2.2.

(3) Check valve Chatter Flow Test. Following 11,000 operational cycles and leak tests, subject the check valve to 240 hours of chatter flow at a flow rate that causes the most chatter (valve flutter). At the completion of the test the check valve shall comply with the ambient temperature leakage test (B.8.2.2) and the strength test(B.8.2.1).

B.8.2.4 Salt Corrosion Resistance Test

AISI series 300 Austenitic stainless steels are exempt from corrosion resistance testing. Materials used in valve units shall be subjected by the test agency to this test except where the applicant submits declarations of results of tests carried out on the material provided by the manufacturer.

The component shall be supported in its normally installed position and exposed for 150 hours to a salt spray (fog) test as specified in ASTM B117 (Standard Practice for Operating Salt Spray (Fog) Apparatus). If the component is expected to operate in vehicle underbody service conditions, then it shall be exposed for 500 hours to the salt spray (fog) test. The temperature within the fog chamber shall be maintained at 30-35^{o}C). The saline solution shall consist of 5 percent sodium chloride and 95 percent distilled water, by weight. Immediately following the corrosion test, the sample shall be rinsed and gently cleaned of salt deposits, examined for distortion, and then shall comply with the requirements of the ambient temperature leakage test specified in B.8.2.2.

B.8.2.5 Vehicle Environment Test

Resistance to degradation by exposure to automotive fluids may be determined by the following test, by comparable published data, or by known properties (e.g. 300 series stainless steel). The decision about the applicability of test data and known properties will be at the discretion of the testing authority.

(1) The inlet and outlet connections of the valve unit shall be connected or capped in accordance with the manufacturers installation instructions. The external surfaces of the valve unit shall be exposed for 24 hours at 20 (+5)oC to each of the following fluids:

- Sulfuric acid - 19 percent solution by volume in water;
- Sodium hydroxide - 25 percent solution by weight in water
- Ammonium nitrate - 28 percent by weight in water; and
- Windshield washer fluid (50 percent by volume methyl alcohol and water).

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

(2) After exposure to each chemical, the component shall be wiped off and rinsed with water and examined. The component shall not show signs of mechanical degradation that could impair the function of the component such as cracking, softening, or swelling. Cosmetic changes such as pitting or staining are not considered failures.

(3) At the conclusion of all exposures, the unit(s) shall comply with the requirements of the ambient temperature leakage test (B.8.2.2) and the strength test (B.8.2.1).

B.8.2.6 Atmospheric Exposure Test

The atmospheric exposure test applies to qualification of check valves; it does not apply to qualification of automatic shut-off valves.

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

(2) All elastomers shall demonstrate resistance to ozone by one or more of the following:

- 33

Deleted: <#>Specification of elastomer compounds with established excellent resistance to ozone.¶
Component testing in accordance with ISO 1431/1, ASTM D1149, or equivalent test methods

B.8.2.7 Electrical Tests

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

(1) Abnormal Voltage Test. Connect the solenoid valve to a variable DC voltage source. Operate the solenoid valve as follows:

(a) at 1.5 times the rated voltage establish equilibrium (steady state temperature) hold for one hour.

(b) Increase the voltage to two times the rated voltage or 60 volts whichever is less and hold for one minute.

(c) Any failure must not result in external leakage, open valve, or a similar unsafe condition.

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

(2) Insulation Resistance Test**.** Apply 1,000 V D.C. between the power conductor and the component casing for at least two seconds. The minimum allowable resistance for that component shall be 240 kΩ.

B.8.2.8 Vibration Test

Vibrate the valve unit, pressurized to its 100% NWP with hydrogen and sealed at both ends, for 30 minutes along each of the three orthogonal axes at the most severe resonant frequencies. The most severe resonant frequencies shall be determined by the following: acceleration of 1.5 g with a sweep time of 10 minutes, within a sinusoidal frequency range of 10 to 500Hz. If the resonance frequency is not found in this range the test shall be conducted at 500 Hz. Following this test, each sample shall not show visible exterior damage that indicates that the part is unsuitable for use. At the completion of the test, the unit shall comply with the requirements of the ambient temperature leakage test specified in B.8.2.2.

B.8.2.9 Stress Corrosion Test

Brass valves with a history of satisfactory field experience shall be exempt from this requirement if documentation can be submitted to the testing agency to justify exemption to this requirement. Brass valves for which a satisfactory declaration of properties is not submitted shall be tested.

The brass unit shall be subjected to the stresses normally imposed on it as a result of assembly. The component shall be degreased and then continuously exposed for ten days to a moist ammonia-air mixture maintained in a glass chamber having a glass cover. Aqueous ammonia having a specific gravity of 0.94 shall be maintained at the bottom of the glass chamber below the sample at a concentration of 21.2 ml per liter of chamber volume. The sample shall be positioned 38 mm (1.5 in) above the aqueous ammonia solution and supported in an inert tray. The moist ammonia-air mixture shall be maintained at atmospheric pressure with the temperature constant at +35(±2)ºC. Brass units shall not exhibit cracking or delamination due to this test.

B.8.2.10 Pre-Cooled Hydrogen Exposure Test

The valve unit shall be subjected to pre-cooled hydrogen gas at -40 ºC at a flow rate of 30 g/s at external temperature of 20(±5) ºC for a minimum of three minutes. The unit shall be de-pressurized and re-pressurized after a two minute hold period. This test shall be repeated ten times. This test procedure shall then be repeated for an additional ten cycles, except that the hold period shall be increased to 15 minutes. The unit shall then comply with the requirements of the ambient temperature leakage test specified in B.8.2.2.