SGS 6 10 Revision.1

Comparison of gaseous fuel tank standards

Prepared by ISO

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Comparison of the gaseous fuel tank standards

ISO 15869	JARI S001	EC Regulation 79/2009 Annex 4, Appendix 2	SAE J2579	OICA proposal
Title	**Title**	**Title**	**Title**	**Title**
Gaseous hydrogen and hydrogen blends —Land vehicle fuel tanks	Technical Standard For Containers Of Compressed Hydrogen Vehicle Fuel Devices	Requirements for hydrogen containers designed to use compressed (gaseous) hydrogen	Technical information report for Fuel systems in Fuel Cell and other Hydrogen Vehicles	Draft proposal for compressed hydrogen storage requirements
Scope	**Scope**	**Scope**	**Scope**	**Scope**
This International Standard specifies the requirements for lightweight refillable fuel tanks intended for the on-board storage of high-pressure compressed gaseous hydrogen or hydrogen blends on land vehicles. This International Standard is not intended as a specification for fuel tanks used for solid, liquid hydrogen or hybrid cryogenic-high pressure hydrogen storage applications. This International Standard is applicable for fuel tanks of steel, stainless steel, aluminium or non-metallic construction material, using any design or method of manufacture suitable for its specified service conditions. This Standard applies to the following types of fuel tank designs: ○ Type 1 – Metal fuel tanks; ○ Type 2 – Hoop wrapped composite fuel tanks with a metal liner; ○ Type 3 – Fully wrapped composite fuel tanks with a metal liner; ○ Type 4 – Fully wrapped composite fuel tanks with no metal liner.	Of the technical contents which should fulfill the technical requirements prescribed in Article 3, Article 6 and Article 7 of the Safety Regulations for Containers (MITI Ordinance No. 50 of 1966) (hereinafter "Regulations"), this Technical Standard for Containers of Compressed Hydrogen Vehicle Fuel Devices (hereinafter "Standard") describes as specifically as possible the following numbered items, which are containers for compressed hydrogen vehicle fuel devices (hereinafter referred to collectively as "Container") manufactured as items not filled from the date specified by the container manufacturer within a period not exceeding 15 years, or from the date on which 15 years have elapsed, calculating from the day prior to the day, month and year displayed by stamping, etc., based on Article 62 or on Item 9, Paragraph 1, Article 8 of the Regulations. (1) Compound containers made of metallic liner for compressed hydrogen vehicle fuel devices. In these containers the minimum liner rupture pressure is less than 125% of the maximum filling pressure (hereinafter "VH3 container"). These containers are limited to full wrap containers. (2) Compound containers made of plastic liner for compressed hydrogen vehicle fuel devices (hereinafter "VH4 container").	This Appendix describes the requirements and test procedures for hydrogen containers designed to use compressed (gaseous) hydrogen.	The purpose of this document is to define design, construction, operational, and maintenance requirements for hydrogen fuel storage and handling system in on-road vehicles. Performance-based requirements for verification of design prototype and production hydrogen storage and handling systems are also defined in this document. Complementary test protocols (for use in type approval or self-certification) to qualify design (and/or production) as meeting the specified performance requirements are described. Crashworthiness of hydrogen storage and handling systems is beyond the scope of this document. SAE J2578 includes requirements relating to crashworthiness and vehicle integration for fuel cell vehicles. It defines recommended practices related to the integration of hydrogen storage and handling systems, fuel cell system, and electrical systems into the overall fuel cell vehicle. NOTE: Ultimate design qualification for crash impact resistance is achieved by demonstrated compliance of the vehicle with applicable regulations. 1.1 Application This SAE Technical Information Report specifies design qualification (performance verification) tests and criteria for hydrogen storage and handling systems. During the 2008-2009 period, it is expected that storage systems within on-road vehicles may not yet incorporate systems consistent with these requirements. Since the 2008-2009 period is one of evaluation and preliminary use of the specifications herein, this document should not be used a requirement to qualify vehicles for on-road use.	This Section specifies the requirements for the compressed hydrogen storage system of hydrogen powered motor vehicles. A compressed hydrogen storage system consists of the pressurized containment vessel(s), thermally-activated pressure relief devices (PRD), shut off devices, and all components, fittings and fuel lines between the containment vessels and these shut off devices that isolate the high pressure hydrogen from the remainder of the fuel system and the environment.

Legend:
Green: Similar approach or requirements
Red: Lower level of safety

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Types	**Types**	**Types**	**Types**	**Types**	**Types**
Covers types 1, 2, 3 and 4	Covers Types 3 and 4	Covers types 1, 2, 3 and 4	Does not specify types of tanks.	Does not specify types of tanks.	The ISO, EC and Japanese documents show that some tests apply only to some types of tanks. In order to avoid performing tests that may not be necessary on some types of tanks, we recommend that we keep the types 1, 2, 3 and 4.
Definitions	**Definitions**	**Definitions**	**Definitions**	**Definitions**	**Definitions**
3.26 **Working pressure**: settled pressure of compressed gas at a uniform temperature of 15 °C in a full fuel tank	N/S	REGULATION (EC) No 79/2009, Article 3. 1. f) **Nominal working pressure**: settled pressure at a uniform temperature of 288K (15°C) for a full container.	3.14 **Nominal working pressure**: container pressure, as specified by the manufacturer, at a uniform gas temperature of 15 °C and full gas content	**Nominal working pressure**: No definition provided	All the definitions describe the same concept. However only ISO use the term *working pressure*. We therefore recommend the use of the term *nominal working pressure*.
Working pressure	**Working pressure**	**Working pressure**	**Nominal working pressure**	**Nominal working pressure**	**Nominal working pressure**
4.3 Working pressure: To be specified by the manufacturer	N/S	2.8.2 To be specified by vehicle manufacturer.	5.2 To be specified by the manufacturer up to 70 MPa.	N/S	We recommended that the GTR requires that the nominal working pressure be specified by the manufacturer.
Maximum filling pressure	**Maximum filling pressure**	**Maximum filling pressure**	**Maximum filling pressure**	**Maximum filling pressure**	**Maximum filling pressure**
4.4 Maximum filling pressure shall not exceed 1,25 times the nominal working pressure	7.10.2 Maximum filling pressure: 35 MPa	N/S	Appendix D: Maximum filling pressure is 1,25 times the nominal working pressure	N/S	The maximum filling pressure is used to guide the designer of the container. This concept is reflected in the testing program and could be left out of the GTR.
Internal capacity	**Internal capacity**	**Internal capacity**	**Internal capacity**	**Internal capacity**	**Internal capacity**
N/S	7.10.3 Internal cubic capacity shall be 360 L or less.	N/S	N/S	N/S	Except for the Japanese standard, all the papers do not specify internal capacity. We recommend that the GTR does not include design restrictions on the internal capacity of the container.
Design temperatures	**Design temperatures**	**Design temperatures**	**Design temperatures**	**Design temperatures**	**Design temperatures**
4.6 Design temperature: -40 ºC to 85 ºC	-40 ºC to 85 ºC	2.8.5.1 Design temperature: –40 °C to +85 °C except for hydrogen components situated either in an internal combustion engine compartment or directly exposed to the operating temperature of an internal combustion engine, for which the temperature range shall be –40 °C to +120 °C.	4.1.2.2 Ambient temperature: -40 ºC to 85 ºC	N/S	The design temperature is used to guide the designer of the container. We recommend the use of the -40 ºC to 85 ºC ratio specified in the ISO, Japanese and SAE papers.

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Service life and number of filling cycles	**Service life and number of filling cycles**	**Service life and number of filling cycles**	**Service life and number of filling cycles**	**Service life and number of filling cycles**	**Service life and number of filling cycles**
4.5 Filling cycles 4.5.1 Except as permitted in 4.5.2, fuel tanks shall be designed for 11 250 filling cycles, representing a 15-year life of use in commercial heavy-duty vehicles. 4.5.2 A reduced number of 5500 filling cycles may be specified for the lifetime of the vehicle, if a counter system is used.	Article 1 Service life: 15 years	2.8.1 Service life: To be specified by the manufacturer, not exceed 20 years. 2.8.6.1. Filling cycles The number of filling cycles shall be 5,000 cycles[1] except as permitted in sections 2.8.6.2.and 2.8.6.3. 2.8.6.2 Provided that a usage monitoring and control system is installed, the number of filling cycles may be less than 5,000 cycles, but not less than 1000 cycles. 2.8.6.3. The vehicle manufacturer may specify a reduced number of filling cycles, calculated by applying the following formula: 1,000 + 200*x, where x is the design service life in years If the filling cycles are not counted, the hydrogen components shall be replaced before exceeding their specified service life.	5.2.2 Durability test cycles: • Commercial vehicles with heavy-duty use: 750 x years of service, but not less than 3 x L/R, and not less than 11 250 cycles. • Personal vehicles: 3 x L/R, but not less than 5500 cycles where L is the lifetime mileage and R, the vehicle range (R).	5.2.2.2 Durability (Hydraulic) Performance test cycles: All vehicles: 3 x L/R, but not less than 5500 cycles where L is the lifetime mileage and R, the vehicle range (R).	Both ISO and SAE specify a number of filling cycles of 11 250, which represent a 15-year life of use in a commercial vehicles. The EC equivalent correspond to 15 000 cycles. The OICA paper allows 5500 cycles for all categories of vehicles, which represent a safety concern for vehicles that will be used in commercial service. As a result, we recommend that the GTR text be aligned with the ISO and SAE recommendation of 11 250 cycles for commercial use. The SAE approach to allow for 5500 cycles for personal vehicles will require that vehicles designed for personal use are identified as such and that measures are put in place to make sure that these vehicles never get into commercial use or that they are removed from service once the maximum number of filling cycles is reached as suggested by the EC. The ISO and EC approach also allows a reduced number of filling cycles (5500 cycles for ISO and 3000 for the EC) provided that a counter system is used. We therefore recommend that in the GTR a reduced number of cycles of 5500 be allowed with either one of the above conditions. The regulators should determine what will be easier for them to enforce.
Burst pressure	**Burst pressure**	**Burst pressure**	**Burst pressure**	**Burst pressure**	**Burst pressure**
7.3 Burst pressure ratio (BPR) Metal: 2,25 X working pressure (WP) Glass: 2,4 WP for type 2, 3,4 WP for type 3 and 3,5 WP for type 4 Aramid: 2,25 WP for type 2, 3,0 WP for type 3 and 3,0 WP for type 4 Carbon: 2,25 WP for WP greater than 35 MPa	Article 2 (4) Minimum rupture pressure: 2,25 x the maximum filling pressure	3.6 Burst pressure ratios (BPR) Metal: 2,25 X nominal working pressure (NWP) Glass: 2,4 NWP for type 2, 3,4 NWP for type 3 and 3,5 NWP for type 4 Aramid: 2,25 NWP for type 2, 3,0 NWP for type 3 and 3,0 NWP for type 4 Carbon: 2,25 NWP for types 2, 3and 4	5.2.2.3.3 New vessel burst pressure 1,8 x nominal working pressure	5.2.2.3.3 Ultimate burst pressure: 1,8 x nominal working pressure	The ISO and EC papers use the same approach for the BPR, which varies with the fibres and type of container. • The BP of a composite container is related to the stress in the fibre. • Different fibres have different stress rupture characteristics, therefore the safety factor should be adjusted accordingly. • The BPR specified in ISO and in the EC papers have been established based on the 40 years of experience of use of composite containers.

[1] The 5000 number of filling cycles in the EC regulation is equivalent to a 15 000 number of filling cycles. All the testing requirements are three times higher than the ISO, SAE and OICA papers.

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Carbon: 2,0 x WP for WP of 35 MPa and higher					The SAE's basic approach is to define maximum possible load and then show that a container despite maximum expectable ageing/degradation, will withstand this load. Maximum load hypothesis is a fuelling process failure. What will differ from one type of container to the other, is the mechanism of degradation, and the rate at which it occurs. This will lead to different BPR for new containers. The problem with SAE's "black box approach" is that the test procedure will have to produce all the ageing that you could see over the life-time of any type of cylinder. To do that, you have to understand all the possible degradation mechanisms sufficiently well to be able to relevantly "accelerate" the ageing so that it takes less time to perform the test than the expected life-time. If the test only reproduces the ageing in part because it doesn't adequately simulate all the ageing factors, you may qualify a tank that will eventually fail before its end of life. The difficulty with such an approach is that you must also factor-in the variability due to manufacturing of initial strength, and also the variability of the degradation rate, parameters which also depend of container type. Finally, measured BP is not necessarily representative of the state of degradation: state of degradation may be advanced without significant reduction of BP – the container is simply closer to the state of instability, i.e. a state beyond which the rate of degradation increases very rapidly, eventually leading to burst. For all the above reasons, it is therefore not practicable to define a single test procedure and a single end-of test BPR. We recommend that the GTR text use the ISO/EC approach where the safety margins on the expected loss of strength is larger on type of containers that are known to be subject to a degradation mechanism that can substantially reduce their strength over life-time, as with glass-fiber/epoxy, than with composites that are known to be subject to much less degradation (e.g. Carbon/epoxy).

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Stress ratio	**Stress ratio**	**Stress ratio**	**Stress ratio**	**Stress ratio**	**Stress ratio**
7.3 Fibre stress ratio Glass: 2,65 WP for type 2, 3,5 WP for type 3 and 3,5 WP for type 4 Aramid: 2,25 WP for type 2, 2,9 WP for type 3 and 3,0 WP for type 4 Carbon: 2,25 WP for WP greater than 35 MPa Carbon: 2,0 x WP for WP of 35 MPa and higher	N/S	3.6 The use of stress ratio in the EC regulation is not clear.	N/S	N/S	In ISO, there is a criteria on both BPR and Stress Ratio. The issue is that with a BPR of 3 for instance, the stress ratio (stress at rupture/stress at nominal pressure) may be less than 3, meaning that the container is closer to the rupture limit at NWP than the BPR suggest. To avoid excessive degradation over time, you need the stress level (SR) to be below a certain specified value throughout the composite. This is why ISO is also looking at the stress ratio. WG 24 of ISO/TC 58/SC 3 is currently investigating these safety factors. We therefore recommend that the GTR include the stress ratio requirements and be revisited once the ISO/TC 58/SC 3 work on ISO/TR 13086 *Factors of safety for composite cylinders* is completed.
Materials	**Materials**	**Materials**	**Materials**	**Materials**	**Materials**
ISO 15869 includes material requirements in Clause 6 (e.g. hydrogen compatibility (6.1 and B.2) exterior coating (8.8 and B.1), tests as part of the qualification tests: 9.2.2 to 9.2.4 Material tests for metal fuel tanks and liners, 9.2.5 Material tests for plastic liners (tensile yield strength, ultimate elongation, softening temperature) and 9.2.6 Resin properties (resin shear strength and resin glass transition temperature)	Article 3 specifies the acceptable materials. Article 4 specifies requirements regarding the acceptable thickness. As part of the qualification tests, Article 9 covers a plastic liner weld part tensile test while Article 20 covers an interlaminate shear test.	The EC regulation includes a series of material requirements in Clause 3.5, in the batch tests 3.9), (hydrogen compatibility (6.1 and B.2) exterior coating (4.1.5), tests as part of the qualification tests (4.1) such as material tests for plastic liners (tensile yield strength, ultimate elongation, softening temperature) and resin properties (resin shear strength and resin glass transition temperature)	5.2.1.5: Appendix F specifies a series of material tests (tensile strength, hydrogen compatibility, tensile properties and softening temperature for plastics, resin shear strength, resin glass temperature, test on exterior coatings)	N/S	Except for the OICA paper, all the documents specify material requirements. The ISO, the EC and the SAE requirements are the same. Since material properties are essential requirements for the safety of containers, we recommend that they be incorporated in the GTR text.

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First series of qualification tests		**First series of qualification tests**		**First series of qualification tests**		**First series of qualification tests (Pneumatic tests)**	**First series of qualification tests (Pneumatic tests)**	**First series of qualification tests**
9.2.15 Extreme temperature pressure cycling (B.14) Minimum number of pressure cycles: 11250 or 5500 cycles- Half of the test to be done at 85 °C and half at -40 °C. Tanks shall show no evidence of leak, rupture or fibre unravelling. Burst pressure shall exceed 80 % of average burst pressure.	✓ (2, 3, 4)	16. Environmental test (conditions differ)	✓ (3, 4)	4.2.9 Extreme temperature pressure cycle Minimum number of pressure cycles: 15000 or 3000 cycles- Half of the test to be done at 85 °C and half at -40 °C. Tanks shall show no evidence of leak, rupture or fibre unravelling. Burst pressure shall exceed 85 % of average burst pressure.	✓ (2, 3, 4)	5.2.2.1.1 Extreme temperature gas cycling[2] Minimum number of pressure cycles: ○ 500 for tanks qualified for personal vehicle use ○ 1000 cycles for tanks qualified for commercial heavy-duty vehicle use	5.2.2.1.1 Extreme temperature Gas cycling[3] Minimum number of pressure cycles: L/R but not less than 500, where L is the lifetime mileage and R, the vehicle range (R).	All the documents require that the container or the hydrogen storage system be subjected to extreme temperature pressure cycling, hydrogen gas cycling, accelerated stress rupture test as well as permeation tests. The SAE and OICA papers required that these tests be carried out in a sequence and that they should be performed on the hydrogen storage system using hydrogen gas. The number of pneumatic pressure cycles is quite lower than the number of hydraulic pressure cycles specified in ISO and in the EC papers. The OICA paper also does not make a distinction between vehicles for personal use and commercial use as it is done in the SAE. Except for the hydrogen gas cycling test, the ISO, Japanese and EC tests are hydraulic tests to be performed on the container. They can be performed in parallel. Considering that both OICA and Japan are looking at alternate ways of testing to reduce the testing time and that they are both considering going back to an approach that is similar to the ISO, Japanese and the EC papers where the tests are hydraulic tests supplemented by material tests, we recommend that the tests should be hydraulic tests done in parallel. Further discussion should be considered for the maximum permeation rate allowed by the permeation test. The acceptance criteria for this test vary from one document to the next.
9.2.19Hydrogen gas cycling (B.18)	✓ (4)	17. Hydrogen gas cycle	✓ (4)	4.2.14 Hydrogen gas cycle	✓ (4 & 3 welded metal liner only)			
9.2.14 Accelerated stress rupture (B.13) 1000 h exposure at 1,25 WP and 85 °C.	✓ (2, 3, 4)	18. Accelerated stress rupture 65 °C –	✓ (3, 4)	4.2.8 Accelerated stress rupture 1000 h exposure at 1,25 WP and 85 °C.	✓ (2, 3, 4)	5.2.2.1.2 Static gas pressure exposure at extreme temperature 1000 h exposure at 1,25 NWP and 85 °C Fuel tanks that are being qualified for commercial heavy-duty vehicle use shall be pressurized with hydrogen gas to 1,35 times the working pressure.	5.2.2.1.2 Static gas pressure exposure at extreme temperature 1000 h exposure at 1,25 NWP and 85 °C	

[2] In SAE and OICA, the extreme temperature gas cycling , the static gas pressure exposure at extreme temperature, the leak/permeation tests are pneumatic tests that are done in a sequence followed by a proof pressure and residual burst pressure tests.

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9.2.17 Permeation (B.16) 500 h test at 1,25 WP at room temperature AC: • 2,00 cc/h/l of water capacity at 35 MPa • 2,8 cc/h/l of water capacity at 70 MPa	✓ (4)	15. Permeation (Measurement until permeation rate is constant)	✓ (4)	4.2.12 Permeation 500 h test at 1,25 WP at 20 °C) AC: • 6,00 cc/h/l of water capacity	✓ (4)	5.2.2.1.3 Leak/Permeation 500 h test at 1,25 NWP and 55 °C AC: 150 cc/min for standard passenger vehicles A leak localized test shall be conducted to confirm that localized leakage, if any, is not capable of sustaining a flame.	5.2.2.1.3 Leak/Permeation 500 h test at 1,25 NWP and 55 °C AC: 150 cc/min for standard passenger vehicles A leak localized test shall be conducted to confirm that localized leakage, if any, is not capable of sustaining a flame.	
Proof pressure N/S		Proof pressure N/S		Proof pressure N/S		5.2.2.1.4 Proof pressure	5.2.2.1.4 Proof pressure	
Residual burst strength 80% of average burst pressure – Included at the end of the accelerated stress rupture (9.2.14 and B.13) and the extreme temperature pressure cycling (9.2.15 and B.14)	✓ (2, 3, 4)	Residual burst strength 75 % of burst pressure	✓ (3, 4)	Residual burst strength 85% of average burst pressure – Included at the end of the accelerated stress rupture (4.2.8) and the extreme temperature pressure cycling (4.2.9)	✓ (2, 3, 4)	5.2.2.1.5 Residual burst strength (80% of new vessel burst pressure)	5.2.2.1.5 Residual burst strength (80% of new vessel burst pressure)	

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Qualification Tests – Second series of tests - To be done on the container		**Qualification Tests – Second series of tests - To be done on the container**		**Qualification Tests – Second series of tests - To be done on the container**		**Qualification Tests – Second series of tests - To be done on the container**	**Qualification Tests – Second series of tests - To be done on the container**	**Qualification Tests – Second series of tests - To be done on the container**
9.2.16 Impact damage (B.15) AC: No leak at 0,2 the expected number of filling cycles (2250 or 1100 cycles). No rupture at expected number of filing cycles (11250 or 5500 cycles)	✓ (3, 4)	14. Drop AC: no leak or rupture after 11250 cycles	✓ (3, 4)	4.2.10 Impact damage AC: No leak at 0,6 the expected number of filling cycles (3000 or 600 cycles). No rupture at three times the expected number of filing cycles (15000 or 3000 cycles)	✓ (3, 4)	5.2.2.2.1 Drop (impact)[3] AC: No leak after the expected number of filling cycles (11250 or 5500 cycles)	5.2.2.2.1 Drop (impact)[3] AC: No leaks after the expected number of filling cycles (5500 cycles).	All the documents require that the container be subjected to an impact damage (drop) test, a surface damage, a chemical exposure, and an ambient temperature extended pressure cycling test. The test procedures are similar and the acceptance criteria vary slightly.
9.2.12 Chemical exposure (B.11) no preconditioning at -40 °C, pendulum impact, exposure to chemicals, pressure cycling at 1,25 WP for at least 0,6 the expected number of filling cycles (3300 or 6650 cycles), 24 hour pressure hold at 1,25 WP.	✓ (2, 3, 4)	16. Environmental test (Immersion test – Chemical exposure conditions differ)	✓ (3, 4)	4.2.6 Chemical exposure no preconditioning at -40 °C, pendulum impact, exposure to chemicals, pressure cycling at 1,25 WP for the expected number of filling cycles (5000 cycles), 24 hour pressure hold at 1,25 NWP.	✓ (2, 3, 4)	5.2.2.2.2 Surface damage and chemical exposure 12 hours of preconditioning at –40 °C, exposure to chemicals, exposure for 48 h at 1.25 NWP before pressure cycling	5.2.2.2.2 Surface damage and chemical exposure no preconditioning at -40 °C, exposure to chemicals for 48 h	The SAE and OICA propose that these tests be done in a sequence. However, considering that both OICA and Japan are looking at alternate ways of testing to reduce the testing time, we recommend that the tests be authorized to be done in parallel and that the ISO acceptance criteria that have the highest level of consensus be used.
9.2.13 Composite flaw tolerance (B.12) No leak or rupture within the first 0,2 expected number of filling cycles (2250 or 1100 cycles) , no rupture during the last 0,8 expected number of filling cycles (up to 11250 or 5500 cycles).	✓ (2, 3, 4)	19. Flaw tolerance (conditions differ: Flaws introduced in liner)	✓ (4)	4.2.7 Composite flaw tolerance No leak or rupture within the first 0,6 expected number of filling cycles (3000 cycles or 600 cycles) , no rupture during the remaining cycles (up to 15000 or 3000 cycles).	✓ (2, 3, 4)			

[3] In SAE, the drop test, the surface damage and chemical exposure, the extended pressure cycling are durability tests to be done in a sequence on the container (not the system) followed by a proof pressure test and residual burst strength test.

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9.2.8 Ambient temperature pressure cycling (B.7) – First part of cycling Tanks shall not leak or rupture before reaching the number of filling cycles (11250 or 5500 cycles).	✓ all	11. Ambient cycling (First part of cycling Tanks shall not leak or rupture before reaching the number of filling cycles (11250 cycles).	✓ (3, 4)	4.2.2 Ambient temperature pressure cycling First part of cycling Tanks shall not leak or rupture before reaching three times the number of filling cycles (15000 or 3000 cycles)	✓ all	5.2.2.2.3 Extended pressure cycling (Test to be done on the system using hydrogen gas or on the tank using non-corrosive fluid.) AC: Containers shall not leak or rupture before the number of durability test cycles specified in 5.2.2 (11250 or 5500 cycles)	5.2.2.2.3 Extended pressure cycling AC: Containers shall not leak or rupture before the number of durability test cycles specified in 5.2.2 (5500 cycles)	
9.2.8 Ambient temperature pressure cycling (B.7) – Second part of cycling. The containers shall be continued to be cycled up to 3 times the number of filling cycles specified in 4.5. In the second part of the test, the tank can leak but not rupture. Tanks achieving 3 times the number of filling cycles (33750 or 16500 cycles) without leak or rupture need not to perform the LBB test.	✓ all	11 Ambient temperature pressure cycling – Second part of cycling. The containers shall be continued to be cycled up to 45000 cycles. In the second part of the test, the tank can leak but not rupture or damage to the fibre.	✓ (3, 4)	4.2.2 Ambient temperature pressure cycling – Second part of cycling. The containers shall be continued to be cycled up to 9 times the number of filling cycles (45 000 or 9000 cycles). In the second part of the test, the tank can leak but not rupture. Tanks achieving 3 times the number of filling cycles (45 000 or 9000 cycles) without leak or rupture need not to perform the LBB test.	✓ all	5.2.2.3.4 New vessel cycle life Three containers shall be cycled to 2 times the number of filling cycles specified in 5.2.2 or until leak occur. If no leaks occur, the new vessel cycle life is established at 2 times the number of filling cycles otherwise the average of the test results for the 3 tanks is to be used for the new vessel cycle life. All 3 tanks shall be within 25 % of the new vessel cycle life.	5.2.2.3.4 Ambient Cycling test in Design Qualification Test (under consideration) Two containers shall be cycled to 4 times the number of filling cycles specified in 5.2.2 (22000 cycles) or until leak occur. There shall be no leaks at less than 5500 cycles. There shall no rupture or damage to the fibre during the rest of the test.	The ISO and EC are looking at leak-before-break requirements. The container may fail by leakage after an acceptable number of filling cycles, but not rupture. OICA is also considering this approach. It is important to keep the LBB concept. We could however remove the LBB test since it can be demonstrated through the ambient pressure cycling test.
9.2.9 Leak-before-break (LBB) (B.8) See above	✓ all	Included in ambient cycling (11)		4.2.3 LBB See above	✓ all	N/S	See above (5.2.2.3.4)	
9.2.18 Boss torque (B.17) The torque specified by the manufacturer is to be applied for the test	✓ (4)	15. Permeation test (a torque of 2 times the torque specified by the manufacturer is to be applied for the test).	✓ (4)	4.2.13 Boss torque test (2 times the torque specified by the manufacturer is to be applied for the test).	✓ (4)	N/S	N/S	This test is covered in ISO, the Japanese and the EC papers. We recommend that it be included in the GTR text. It should be determined if the test should be done at 2 times or at the torque specified by the manufacturer.

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Qualification Tests – Third series of tests		**Qualification Tests – Third series of tests**		**Qualification Tests – Third series of tests**		**Qualification Tests – Third series of tests**	**Qualification Tests – Third series of tests**	**Qualification Tests – Third series of tests**
9.2.10 Bonfire (B.9)(590 °C) - To be carried out on the container with the PRD or on the hydrogen storage system.	✓ all	13. Bonfire (430 °C)	✓ (3,4)	4.2.4 Bonfire (590 °C) - To be carried out on the container with the PRD	✓ all	5.2.2.3.1 Engulfing fire (bonfire) (500 °C) – To be carried out on the system.	5.2.2.3.1 Engulfing fire (bonfire) (Temperature N/S) – To be carried out on the system.	The bonfire test is included in all documents. It should be included in the GTR text.
9.2.11 Penetration (B.10) AC: No rupture	✓ all	N/E		4.2.5 Penetration AC: No rupture	✓ all	5.2.2.3.2 Penetration AC: No rupture	5.2.2.3.2 Penetration AC: No rupture	Except for the Japanese documents, all papers require a penetration test. It should be included in the GTR text.
9.2.7 Hydrostatic burst pressure (B.6) (minimum burst pressure requirements and stress ratios requirements have to be met)	✓ all	10. Hydrostatic burst	✓ (3,4)	4.2.1 Burst	✓ all	5.2.2.3.3 New vessel burst pressure (minimum burst pressure requirements have to be met)	5.2.2.3.3 Ultimate burst pressure minimum burst pressure requirements have to be met)	All documents require that the container be subjected to a hydrostatic burst pressure test. It should be included in the GTR.

Legend:
Green: Similar approach or requirements
Red: Lower level of safety

ISO 15869		JARI S001		EC Regulation 79/2009 Annex 4, Appendix 2		SAE J2579	OICA proposal	Rationale for the recommendations proposed for the GTR
Sampling (Batch) tests		**Sampling (Batch) tests**		**Sampling (Batch) tests**		**Sampling (Batch) tests**	**Sampling (Batch) tests**	**Sampling (Batch) tests**
10.2.2 Hydrostatic burst pressure AC: 90 % of average burst pressure	✓ all	27. Hydrostatic burst AC: 2,25 x the maximum filling pressure	✓ (3,4)	3.9.1.1 Burst test (Meet the burst pressure ratio)		5.2.3.2 a. (90 % of average burst pressure	N/S	Except for OICA, all the papers require the container be subjected to sampling (batch) tests. Batch tests are specified when the manufacturing process is a special process (process, the results of which cannot be entirely verified by a non-destructive test of the product such as welding, painting, etc) These tests are required to make sure that the manufacturing process is maintained under control and that the containers that are produced have not deviated from the design that has been approved as part of the qualification (type) tests. The ISO, Japanese, the EC and the SAE papers all require that the following tests be performed: • Burst test • Pressure cycling at ambient temperature • Material tests The test procedures and acceptance criteria are very similar. They should be included in the text of the GTR.
10.2.3 Periodic ambient temperature pressure cycling Tanks shall not leak or rupture before reaching the number of filling cycles (11250 or 5500 cycles).	✓ all	26. Ambient cycling	✓ (3,4)	3.9.1.1 Ambient temperature pressure cycling Tanks shall not leak or rupture before reaching three times the number of filling cycles (15000 or 3000 cycles)	✓ all	5.2.3.2 b. Pressure cycle AC: Containers shall not leak or rupture before the number of durability test cycles specified in 5.2.2 (11250 or 5500 cycles) and shall show that the pressure cycle life is within 25 % of the design qualified pressure cycle life.	N/S	
10.2.2 Material tests	✓ all	21. Tensile test	✓ (3,4)	10.2.2 Material tests	✓ all	5.2.3.2 c. Material tests	N/S	
Routine (Production) tests		**Routine (Production) tests**		**Routine (Production) tests**		**Routine (Production) tests**	**Routine (Production) tests**	**Routine (Production) tests**
10.1 a) to g) Dimensional inspection, NDE of metallic fuel tanks and liners, examination of welded liners, inspection of plastic liners and hardness tests of metallic fuel tanks and liners	✓ all	22. External appearance, 23. NDE	✓ (3,4)	3.10 Dimensional inspection, NDE of metallic fuel tanks and liners, examination of welded liners, inspection of plastic liners and hardness tests of metallic fuel tanks and liners	✓ all	5.2.3.1.c. to e. Dimensional inspection, NDE, examination of welded liners, and hardness tests of metallic fuel tanks and liners	N/S	Except for OICA, all the papers require the container be subjected to the routine (production) tests. The ISO, Japanese, the EC and the SAE papers all require that the same tests be performed. The test procedures and acceptance criteria are very similar. They should be included in the text of the GTR.
10.1.h) Hydraulic test	✓ all	24. Expansion measurement test	✓ (3,4)	3.10 Hydraulic test	✓ all	5.2.3.1.b. Proof pressure	N/S	

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ISO 15869		JARI S001		EC Regulation 79/2009 Annex 4, Appendix 2		SAE J2579	OICA proposal	Rationale for the recommendations proposed for the GTR
10.1 i) Leak test	✓ (4)	25. Leak test	✓ (4)	3.10 Leak test	✓ (4 & 3 welded metal liner only)	5.2.3.1.a. Leak test	N/S	

Conclusion

All the papers that are being looked at by the HFCV SGS for defining the requirements that apply to the storage containers have similarities that facilitate their comparison. It is fair to say that the ISO and the EC approaches are almost identical. The SAE and the OICA paper use a similar approach except that the OICA paper is further reducing the level of safety of the container by:

- specifying a number of pressure cycles for the expected service performance tests and the durability tests that do not take into account that vehicles could be in commercial use;
- not specifying any material tests
- not specifying any batch tests
- not specifying any routine (production tests).

Both the SAE and OICA proposal make the assumption that a end of life BPR of 1,8 can be used irrelevant of the fibre and type of tanks. The SAE's basic approach is to define maximum possible load and then show that a container despite maximum expectable ageing/degradation, will withstand this load. Maximum load hypothesis is a fuelling process failure. What will differ from one type of container to the other is the mechanism of degradation, and the rate at which it occurs. The problem with SAE's "black box approach" is that the test procedure will have to produce all the ageing that you could see over the life-time of any type of cylinder. To do that, you have to understand all the possible degradation mechanisms sufficiently well to be able to relevantly "accelerate" the ageing so that it takes less time to perform the test than the expected life-time. If the test only reproduces the ageing in part because it doesn't adequately simulate all the ageing factors, you may qualify a tank that will eventually fail before its end of life. The difficulty with such an approach is that you must also you must also factor-in the variability due to manufacturing of initial strength, and also the variability of the degradation rate, parameters which also depend of container type. Finally, measured BP is not necessarily representative of the state of degradation: state of degradation may be advanced without significant reduction of BP – the container is simply closer to the state of instability, i.e. a state beyond which the rate of degradation increases very rapidly, eventually leading to burst.
For all the above reasons, it is therefore not practicable to define a single test procedure and a single end-of test BPR. We recommend that the GTR text use the ISO/EC approach where the safety margins on the expected possible loss of strength is larger on type of containers that are known to be subject to a degradation mechanism that can substantially reduce their strength over life-time, as with glass-fiber/epoxy, than with composites that are known to be subject to much less degradation (e.g. Carbon/epoxy).

Further OICA and Japan recognize that the first series of qualification test (systems- level pneumatic tests done in sequence) are quite extensive and too lengthy. Both are looking at alternate ways of testing that revert back to the ISO/EC approach of using hydraulic tests performed on the containers supplemented by material tests. For all the above reasons, we recommend that the GTR text be extracted from the ISO paper, which represents the higher level of consensus among all the papers being looked at by the HFCV SGS.

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