ISO proposal for the container requirements for the HFCV GTR

5.1 **Storage system**: This section specifies the requirements for the integrity of the fuel container of hydrogen powered motor vehicle. The fuel container can be described the following types of fuel container designs:

— Type 1 – Metal containers;

— Type 2 – Hoop wrapped composite containers with a metal liner;

— Type 3 – Fully wrapped composite containers with a metal liner;

— Type 4 – Fully wrapped composite containers with no metal liner.

5.1.1 **Definitions:** For the purposes of this document, the following terms and definitions apply.

5.1.1.1 **Fully wrapped composite container:** container with an over-wrap having a filament wound reinforcement both in the circumferential and axial direction of the container

5.1.1.2 **Hoop-wrapped composite container:** container with an over-wrap having a filament wound reinforcement in a substantially circumferential pattern over the cylindrical portion of the liner so that the filament does not carry any significant load in a direction parallel to the longitudinal axis of the container

5.1.1.3 **Hydrogen storage system**: system on a land vehicle comprised of the container and all closure devices (e.g. shut-off valves, check valves and thermally activated pressure relief devices) and piping that contains hydrogen at NWP

5.1.1.4 **Nominal working pressure (NWP):** settled pressure of compressed gas at a uniform temperature of 15 °C in a full container

5.1.1.5 **Stress ratio**: stress in fibre at specified minimum burst pressure divided by stress in fibre at NWP

5.1.2 **NWP:** The NWP shall be specified by the container manufacturer for gaseous hydrogen and hydrogen blends settled at a temperature of 15 °C.

5.1.3 **Filling cycles**: Containers shall be designed for 11 250 fill cycles, representing a 15-year life of use in commercial heavy-duty vehicles. A reduced number of 5 500 filling cycles may be specified for the lifetime of the vehicle. Containers with the reduced number of filling cycles shall only be provided with a tamper-proof counter system that records the number of fill cycles and terminates usage of the container before the reduced number of fill cycles is exceeded.

5.1.4 **Design temperature**: Containers shall be suitable for use in the following material temperature range: -40 °C to 85 °C.

5.1.5 **Burst pressure and fibre stress ratio**: The minimum actual burst pressure of the container shall not be less than the values given in Table 1. Composite reinforcement used on containers shall also meet the minimum stress ratio requirements of Table 1.

Table 1 — Minimum stress ratios and burst pressures

Construction	**Minimum stress ratio**			**Minimum actual burst pressure**[a]			
	Type 2	**Type 3**	**Type 4**	**Type 1**	**Type 2**[b]	**Type 3**	**Type 4**
All-Metal				2,25			
Glass	2,65	3,5	3,5		2,4	3,4	3,5
Aramid	2,25	3,0	3,0		2,25	2,9	3,0
Carbon (NWPs less than 35 MPa)	2,25	2,25	2,25		2,25	2,25	2,25
Carbon (NWPs greater than or equal to 35 MPa)	2,0	2,0	2,0		2,0	2,0	2,0
Hybrid	[c]						

[a] Burst pressures are expressed as a factor of NWP.
[b] For Type 2 designs, the un-reinforced metal liner shall have a minimum burst pressure of 1,25 NWP.
[c] The stress ratio requirements for each individual fibre type shall be in accordance with the values given above.

5.1.6 Material tests**:** Type 1, 2, 3 and 4 designs shall be subjected to the applicable material tests listed in Table 2.

Table 2 — Material tests

Test		Number of containers required for testing	Applicable to type			
			1	2	3	4
5.1.6.1 to 5.1.6.3	Material tests for metal containers and liners	1 container or liner	✓	✓	✓	
5.1.6.4	Hydrogen compatibility	1	✓	✓	✓	
5.1.6.5	Material tests for plastic liners	1 liner				✓
5.1.6.6	Resin properties	composite samples		✓	✓	✓
5.1.6.7	Coating tests	1	✓	✓	✓	✓

5.1.6.1 **Material tests for steel containers and liners**: If the container or liner is made of steel, appropriate material tests in accordance with 10.2 to 10.4 of ISO 9809-1:1999, or 10.2 to 10.4 of ISO 9809-2:2000, shall be carried out. The tensile strength shall meet the manufacturer's design specifications. For Type 1 and Type 2 designs the steel elongation shall be at least 14 %. For Type 3 designs the tensile strength and elongation shall meet the manufacturer's design specifications.

5.1.6.2 **Material tests for aluminium alloy containers and liners**: For Type 1 containers and Type 2 liners using aluminium alloy, appropriate material tests as required in ISO 7866:1999, 10.2 and 10.3, as well as Annexes A and B shall be carried out on one container or liner. The materials properties shall meet the manufacturer's design specifications. The elongation shall be at least 12 %.

For Type 3 liners using aluminium alloy, materials tests as required in ISO 7866:1999, 10.2 and Annex B shall be carried out on one liner. The materials properties, including elongation, shall meet the manufacturer's design specifications.

For Type 3 liners using welded aluminium alloys, the requirements in 7.2.3 to 7.2.7 of EN 12862:2000 shall be followed, as well as Annexes A and B, excluding B2.2 thereof.

5.1.6.3 **Material tests for stainless steel liners** Materials used for stainless steel liners shall follow the requirements in 7.1.2.1 and 7.1.2.4 of EN 1964-3:2000. Materials used for welded stainless steel liners shall follow the requirements in 8.4 to 8.7 of EN 13322-2:2003.

5.1.6.4 **Hydrogen compatibility of metal tanks and liners**: The hydrogen compatibility of metal tanks and liners hydrogen shall be demonstrated on one container or liner in accordance with the procedure below. Steels that conform to 6.3 and 7.2.2 of ISO 9809-1:1999 and aluminium alloys that conform to 6.1 and 6.2 of ISO 7866:1999 are exempted from this test.

Hydrogen compatibility of the container or liner material shall be demonstrated by one of the following:

a) using a material known to be resistant to hydrogen embrittlement under the prevailing service conditions, for example as specified in ISO 11114-1 or ISO/TR 15916;

b) demonstrating the hydrogen compatibility of the material in accordance with ISO 11114-4 or an equivalent comparative test method for resistance to sustained hydrogen loading, and performing a fatigue test in a hydrogen environment. An example of an acceptable fatigue test includes the hydrogen gas cycle testing of a complete liner between the pressure levels that provides an equivalent liner wall stress as would be present in the container at 2 MPa and 1,25 NWP; or

c) by conducting hydrogen pressure cycle tests with a complete container from 2 MPa to 1,25 NWP. The container shall not fail before reaching the number of filling cycles specified in 5.1.3.

In all cases, the reduction of cycle life due to the effect of hydrogen exposure shall be considered.

5.1.6.5 **Material tests for plastic liners**: The tensile yield strength and ultimate elongation of plastic liner material shall be determined at – 40 °C in accordance with ISO 527-2. The test results shall demonstrate the ductile properties of the plastic liner material at temperatures of – 40 °C or lower by meeting the values specified by the manufacturer.

The softening temperature of polymeric materials from finished liners shall be tested in accordance with ISO 306. The appropriate method to be applied should be specified by the supplier of the polymeric material. The softening temperature shall be at least 100 °C.

5.1.6.6 **Resin properties tests**: The resin shear strength shall be tested on three sample coupons representative of the composite over-wrap in accordance with ASTM D 2344. Following a 24-hour water boil the composite shall have a minimum shear strength of 13,8 MPa. The resin glass transition temperature shall also be determined in accordance with ASTM D 3418, or equivalent. The test results shall be within the manufacturer's specifications.

5.1.6.7 **Coating test**: If a protective coating is part of the design, the coatings shall be evaluated in accordance with the following procedure:

a) adhesion testing in accordance with ISO 4624. A minimum rating of 4 shall be obtained when measured using Method A or B, as appropriate;

b) flexibility in accordance with ASTM D 522, using Test Method B with a 12,7 mm mandrel at the specified thickness at – 20 °C. Samples for the flexibility test shall be prepared in accordance with ASTM D 522. There shall be no visually apparent cracks;

c) impact resistance in accordance with ASTM D 2794. The coating at room temperature shall pass a forward impact test of 18 J;

d) chemical resistance in accordance with ASTM D 1308 except as identified in the following. The tests shall be conducted using the open spot test method and 100-hour exposure to a 30 % sulphuric acid solution (battery acid with specific gravity of 1,219) and 24-hour exposure to a polyalkalene glycol (e.g. brake fluid). There shall be no evidence of lifting, blistering or softening of the coating. The adhesion shall meet a rating of 3 when tested in accordance with ISO 4624;

e) light and water exposure using a UVA-340 lamp in accordance with ASTM G 154 for a minimum 1 000 hours. There shall be no evidence of blistering, and adhesion shall meet a rating of 3 when tested in accordance with ISO 4624. The maximum gloss loss shall be less than or equal to 20 %;

f) salt spray exposure in accordance with ASTM B 117 for a minimum 500 hours. Undercutting shall not exceed 3 mm at the scribe mark. There shall be no evidence of blistering, and adhesion shall meet a rating of 3 when tested in accordance with ISO 4624;

g) resistance to chipping at room temperature in accordance with ASTM D 3170. The coating shall have a rating of 7A or better, and there shall be no exposure of the substrate.

5.1.7 Type (qualification) tests

5.1.7.1 **Qualification of new designs**: Type tests shall be conducted on each new design, on finished containers that are representative of normal production, complete with identification marks. All containers subjected to type tests shall be made unserviceable after the tests.

5.1.7.2 **Tests to be performed:** Type 1, 2, 3 and 4 designs shall be subjected to the applicable type tests listed in Table 3.

Table 3 — Qualification tests

Test		Number of containers required for testing	Applicable to type			
			1	2	3	4
5.1.7.3	Extreme temperature pressure cycling	1		✓	✓	✓
5.1.7.4	Hydrogen gas cycling	1				✓
5.1.7.5	Accelerated stress rupture	1		✓	✓	✓
5.1.7.6	Permeation	1				✓

Test		Number of containers required for testing	Applicable to type			
			1	2	3	4
5.1.7.7	Impact damage	1, 2 or 3			✓	✓
5.1.7.8	Chemical exposure	1		✓	✓	✓
5.1.7.9	Composite flaw tolerance	1		✓	✓	✓
5.1.7.10	Ambient temperature pressure cycling	2	✓	✓	✓	✓
5.1.7.11	Boss torque	1				✓
5.1.7.12	Bonfire	1	✓	✓	✓	✓
5.1.7.13	Penetration	1	✓	✓	✓	✓
5.1.7.14	Hydrostatic burst pressure	3 plus 1 liner	✓	✓ ✓	✓	✓

5.1.7.3 **Extreme temperature pressure cycling test:** For Type 2, Type 3 and Type 4 designs, one finished container with the composite wrapping free of any protective coating shall be cycle tested in accordance with the following procedure.

a) Fill with a non-corrosive fluid such as oil, inhibited water or glycol, and condition for 48 hours at a pressure of less than 2 MPa, not less than 85 °C, and 95 % or greater relative humidity. The intent of this requirement shall be deemed met by spraying with a fine spray or mist of water in a chamber held at 85 °C.

b) Hydrostatically pressurize for 0,5 times the number of filling cycles specified in 5.1.3 between not more than 2 MPa nor less than 1,25 NWP at 85 °C or higher as measured on the container surface, and 95 % or greater relative humidity.

c) Condition the container and fluid at – 40 °C or lower as measured in the fluid and on the container surface.

d) Pressurize from not more than 2 MPa to not less than NWP for 0,5 times the number of filling cycles specified in 5.1.3, at – 40 °C or lower. For Type 4 designs, recording instrumentation shall be provided to ensure the minimum temperature of the fluid is maintained during the low temperature cycling.

The pressure cycling rate of b) shall not exceed 10 cycles per minute. The pressure cycling rate of d) shall not exceed 2 cycles per minute unless a pressure transducer is installed directly within the container. During this pressure cycling, the container shall show no evidence of rupture, leakage or fibre unravelling.

Following pressure cycling at extreme temperatures, containers shall be hydrostatically pressured to failure in accordance with 5.1.7.14 , and achieve a minimum burst pressure that exceeds 80 % of the average of the results obtained during the hydrostatic burst test of 5.1.7.14.

5.1.7.4 **Hydrogen gas cycling test**: For Type 4 designs, one container shall be pressure cycled using compressed hydrogen gas from less than 2 MPa to not more NWP for 1 000 cycles, or for the number of filling cycles specified in 5.1.3. The filling time shall be less than or equal to five minutes, and the total cycle time shall be less than or equal to one hour. Every 100 cycles, there shall be a 24-hour hold period at NWP.

Unless otherwise specified by the manufacturer, temperatures during the test shall be monitored using a thermocouple attached to the metal end boss at both ends of the container. If only one boss end is exposed, the second temperature shall be obtained by inserting a probe into the container to measure the gas temperature at the opposite end. Care shall be taken to ensure that temperatures during filling and venting do not exceed the defined service conditions.

For Type 4 containers subjected to the 1 000 cycles, following completion of the hydrogen gas cycling, the container shall be leak tested in accordance with 5.1.9 i), then sectioned and the plastic liner and liner/end boss interface inspected for evidence of any deterioration, such as fatigue cracking or electrostatic discharge. If there is evidence of deterioration, another container of the same design shall be hydrogen gas cycle tested for the number of filling cycles specified in 5.1.3 without failure.

NOTE: Special consideration shall be given to safety when conducting this test. Prior to conducting this test, containers of the same design shall have successfully passed the test requirements of 5.1.7.14 (hydrostatic burst pressure test), 5.1.7.10 (ambient temperature pressure cycling) and 5.1.7.6(permeation test). The container to be used in the test shall have successfully passed the test requirements of 5.1.9 h) (hydraulic test).

5.1.7.5 **Accelerated stress rupture test**: For Type 2, Type 3 and Type 4 designs, one container shall be hydrostatically pressurized to 1,25 NWP at 85 °C. The container shall be held at this pressure and temperature for 1 000 hours. The container shall then be pressured to burst in accordance with the procedure specified in 5.1.7.14, except that its burst pressure shall exceed 80 % of the average of the results obtained during the hydrostatic burst test of 5.1.7.14.

5.1.7.6 **Permeation test**: For Type 4 designs, one finished container shall be filled with compressed hydrogen to NWP, placed in a sealed chamber at ambient temperature, and monitored for permeated flow for 500 hours. The steady state permeation rate for hydrogen gas shall be less than 2,00 cm^3 of hydrogen per hour per litre water capacity at 35 MPa, and 2,8 cm^3 per hour per litre water capacity at 70 MPa. At NWPs other than those stated, the permeation rate should be interpolated or extrapolated based on the above permissible permeation rates.

5.1.7.7 **Impact damage test**: For Type 3 and Type 4 designs, one or more finished containers shall be drop tested at ambient temperature without internal pressurization or attached valves. All drop tests may be performed on one container, or individual impacts on a maximum of 3 containers. A plug may be inserted in the threaded ports to prevent damage to the threads and seal surfaces. The surface onto which the containers are dropped shall be a smooth horizontal concrete pad or similar rigid surface. The container(s) shall be tested in accordance with the following procedure:

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 488 J, but in no case shall 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°, with its centre of gravity 1,8 m above the impact surface. However, if the bottom is closer to the impact surface than 0,6 m, the drop angle shall be changed to maintain a minimum height of 0,6 m and a centre of gravity of 1,8 m above the impact surface.

No attempt shall 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). Following the drop impact, the containers shall then be filled with a non-corrosive fluid such as oil, inhibited water or glycol, and pressure cycled from not more than 2 MPa to not less than 1,25 NWP at ambient temperature for the number of filling cycles specified in 5.1.3. The container(s) shall not leak or rupture within 0,2 times the number of filling cycles specified in 5.1.3, but may fail by leakage during the remaining test cycles.

5.1.7.8 **Chemical exposure test**: For Type 2, Type 3 and Type 4 designs, the following chemical exposure test shall be performed on one finished container, including the coating if applicable. The upper section of the container shall be divided into five distinct areas and marked for pendulum impact preconditioning and fluid exposure (see Figure 1). The five areas shall each be nominally 100 mm in diameter. The five areas do not need to be oriented along a single line, but they shall not overlap.

Figure 1 — Container orientation and layout of exposure areas

The approximate centre of each of the five areas shall be preconditioned by the impact of a pendulum body. The steel impact body of the pendulum shall have the shape of a pyramid with equilateral triangle faces and a square base, the summit and the edges being rounded to a radius of 3 mm. The centre of percussion of the pendulum shall coincide with the centre of gravity of the pyramid; its distance from the axis of rotation of the pendulum being 1 m and the total mass of the pendulum referred to its centre of percussion shall be 15 kg. The energy of the pendulum at the moment of impact shall not be less than 30 J. During pendulum impact, the container shall be held in position by the end bosses or by the intended mounting brackets. The container shall not be under pressure during preconditioning.

Each of the five preconditioned areas shall be exposed to one of five solutions (each solution shall be used and applied to only one preconditioned area). The five solutions are the following:

- volume fraction of 19 % sulphuric acid in water;
- mass fraction of 25 % sodium hydroxide in water;
- volume fraction of 5 % methanol in gasoline;
- mass fraction of 28 % ammonium nitrate in water;
- volume fraction of 50 % methyl alcohol in water (windshield washer fluid).

During the exposure, orient the test cylinder 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 exposure areas. Apply an amount of the test fluid to the glass wool sufficient to ensure that the pad is wetted evenly across its surface and through its thickness for the duration of the test.

The container shall then be filled with a non-corrosive fluid such as oil, inhibited water or glycol, and hydraulically pressure cycled from not more than 2 MPa to not less than 1,25 NWP for at least 0,6 times the number of filling cycles specified in 5.1.3. After pressure cycling, the container shall be pressurized to 1,25 NWP, and held at that pressure a minimum of 24 hours. When burst tested in accordance with 5.1.7.14, the container shall have a burst pressure that exceeds 1,8 NWP.

5.1.7.9 **Composite flaw tolerance test**: For Type 2, Type 3 and Type 4 designs, one finished container, complete with any protective coating, shall have flaws in the longitudinal direction cut into the composite. The flaws shall be greater than the visual inspection limits specified by the manufacturer. As a minimum, one flaw shall be 25 mm long and 1,25 mm in depth, and another flaw shall be 200 mm long and 0,75 mm in depth, cut in the longitudinal direction into the container sidewall. The flawed container shall then be filled with a non-corrosive fluid such as oil, inhibited water or glycol, and pressure cycled from not more than 2 MPa to not less than 1,25 NWP at ambient temperature, for the number of filling cycles specified in 5.1.3. The container shall not leak or rupture within the first 0,2 times the number of filling cycles specified in 5.1.3, but may fail by leakage during the last 0,8 times the number of filling cycles specified in 5.1.3.

5.1.7.10 **Ambient temperature pressure cycling test**: For all designs, two containers shall be pressure cycled at ambient temperature as follows:

a) fill the container with a non-corrosive fluid such as oil, inhibited water or glycol;

b) cycle the pressure in the container between not more than 2 MPa and not less than 1,25 NWP at a rate not to exceed 10 cycles per minute.

The container shall be pressure cycled until failure or to a minimum of 3 times the number of filling cycles specified in 5.1.3. The containers shall not leak before reaching the number of filling cycles specified in 5.1.3. Containers shall not fail before reaching 3 times the number of filling cycles specified in 5.1.3.

5.1.7.11 **Boss torque test**: For Type 4 designs, one container container shall be restrained against rotation and the torque specified by the manufacturer shall be applied to each end boss of the container. The torque shall be applied first in the direction to tighten a threaded connection, then in the untightening direction, and finally again in the tightening direction. The container shall then be subjected to a leak test in accordance with 5.1.9 i) followed by a burst test in accordance with 5.1.7.14.

5.1.7.12 **Bonfire test:** For all designs, the container complete with the container manufacturer specified fire protection system shall be subjected to the bonfire test as follows:

5.1.7.12.1 **Set-up**: The container shall be placed horizontally with the container bottom approximately 100 mm above the fire source. Metallic shielding of at least 0,4 mm thickness shall be used to prevent direct flame impingement on container valves, fittings, and/or pressure relief devices. The metallic shielding shall not be in direct contact with the container manufacturer specified non-reclosing thermally activated pressure relief devices. Any failure during the test of a valve, fitting or tubing that is not part of the container manufacturer specified fire protection system shall invalidate the result.

5.1.7.12.2 **Fire source**: A uniform fire source of 1,65 m in length shall provide direct flame impingement on the container surface across its entire diameter (width). The arrangement of the fire shall be recorded in detail to ensure the rate of heat input to the container is reproducible. Any failure or inconsistency of the fire source during a test shall invalidate the result.

5.1.7.12.3 **Temperature and pressure measurements**: Surface temperatures shall be monitored by at least three thermocouples located on the bottom surface of the container and spaced not more than 0,75 m apart. Metallic shielding of 0,4 mm minimum thickness shall be used to prevent direct flame impingement on the thermocouples. Thermocouple temperatures and the container pressure shall be recorded at intervals of every ten seconds or less during the test.

5.1.7.12.4 **Test requirements**: The container shall be pressurized to NWP with hydrogen and tested in the horizontal position. Following ignition, the fire shall produce flame impingement on the surface of the container along the 1,65 m length of the fire source and across the container diameter. Within 5 minutes of ignition, the temperature of at least one thermocouple shall indicate a minimum temperature of 590 °C. This minimum temperature shall be maintained for the remaining duration of the test. For containers of length of 1,65 m or less, the centre of the container shall be positioned over the centre of the fire source. For containers of length greater than 1,65 m, the container shall be positioned in accordance with the following procedure:

a) if the container is fitted with a non-reclosing thermally activated pressure relief device at one end, the fire source shall commence at the opposite end of the container;

b) if the container is fitted with non-reclosing thermally activated pressure relief devices at both ends, or at more than one location along the length of the container, the centre of the fire source shall be centred midway along the longest container span without non-reclosing thermally activated pressure relief devices;

c) if the container is additionally protected with thermal insulation, two fire tests at NWP shall be performed, one with the fire centred midway along the container length with the non-reclosing thermally activated pressure relief devices removed, and the other with the fire commencing at one of the ends of a second container with the non-reclosing thermally activated pressure relief devices installed. If necessary to ensure minimum bonfire temperatures are achieved during the test, the thermocouples on the bottom surface of the container shall instead be placed on the bottom external surface of the thermal insulation.

The container shall vent through the non-reclosing thermally activated pressure relief device, part of the container manufacturer specified fire protection system. If the container vents through a fitting or valve other than this non-reclosing thermally activated pressure relief device, the test shall be repeated. For containers that are additionally protected with a thermal insulation, when the thermal insulation alone is tested under 5.1.7.12.4 c), the container shall not fail when exposed to a bonfire of 20 minutes duration. The results shall summarize the elapsed time from ignition of the fire to the start of venting through non-reclosing thermally activated the pressure relief device(s), and the maximum pressure and time of evacuation until a pressure of less than 1 MPa is reached.

5.1.7.13 **Penetration test**: For all designs, one container pressurized to NWP ± 1 MPa with compressed hydrogen gas shall be penetrated by an armour piercing bullet or impactor with a diameter of 7,62 mm or greater. The bullet shall completely penetrate at least one sidewall of the container. The bullet or impactor shall impact the sidewall at an approximate angle of 45° to the container centreline. The container shall not rupture.

5.1.7.14 **Hydrostatic burst pressure test**: For Type 2 designs, one liner shall be hydrostatically pressurized to failure. The burst pressure shall exceed 1,25 NWP.

For all designs, three containers shall be hydrostatically pressurized to failure. For each container, the burst pressure shall exceed the specified minimum burst pressure specified in Table 1. In no case shall the burst pressure be less than the value necessary to meet the stress ratio requirements in Table 1. The average of the burst pressure results of the three containers shall be recorded for future reference.

For this test, the container or liner shall be filled with a fluid such as water and the pressure gradually increased until failure. It shall be ensured that the pressure measuring device is monitoring the true pressure, particularly when the pressurization rate exceeds 0,35 MPa/s. Alternatively, there shall be a five second hold at the minimum design burst pressure.

5.1.8 Batch tests

5.1.8.1 **General**: Batch tests shall be carried out on each batch of containers. The containers and liners required for testing shall be randomly selected from each batch. All containers subjected to batch tests shall be made unserviceable after the tests.

5.1.8.2 **Tests required**: One container shall be subjected to the hydrostatic burst pressure test in accordance with 5.1.7.14. The container burst pressure shall exceed the specified minimum burst pressure and stress ratio requirement specified in Table 1. In addition, the burst pressure shall exceed 90 % of the average of the results obtained during the hydrostatic burst test of 5.1.7.14.

One container shall be pressure cycled from not more than 2 MPa to not less than 1,25 NWP at a rate not to exceed 10 cycles per minute for the number of filling cycles specified in 5.1.3. For Type 4 designs, prior to pressure cycling, the end boss shall be torque tested in accordance with 5.1.7.11, and following the required pressure cycling, the container shall be leak tested in accordance with the method specified in 5.1.9 i) , and meet the requirements therein. If any containers fail to meet the minimum cycle life requirement of the number of filling cycles specified in 5.1.3, then the cause of failure shall be determined and corrected following the procedures in 5.1.8.3. The pressure cycle test shall then be repeated on an additional three containers from that batch. Should any of the three additional containers fail to meet the minimum pressure cycling requirement of the number of filling cycles specified in 5.1.3, then the batch shall be rejected. The manufacturer shall demonstrate that containers produced since the last successful batch test meet all batch test requirements.

For Type 1, Type 2 and Type 3 designs, a further container, liner, or sample representative of a finished container or liner, shall be subjected to the following tests:

a) verification of the critical dimensions of the design;

b) tensile tests for steel containers or liners, in accordance with 10.2 of ISO 9809-1:1999, or 10.2 of ISO 9809-2:2000 as appropriate. Tensile tests for aluminium alloy containers or liners, in accordance with 10.2 of ISO 7866:1999. Tensile tests for stainless steel liners, in accordance with 7.1.2.1 of EN 1964-3:2000. Tensile tests for welded stainless steel liners, in accordance with 8.4 of EN 13322-2:2003. Tensile tests for welded aluminium liners, in accordance with 7.2.3 and 7.2.4 of EN 12862:2000. The test results shall satisfy the requirements of the design;

c) impact tests for steel containers or liners, in accordance with 10.4 of ISO 9809-1:1999, or 10.4 of ISO 9809-2:2000, as appropriate, and meet the requirements therein. Impact tests for stainless steel liners in accordance with 7.1.2.4 of EN 1964-3:2000, and meet the requirements therein. Impact tests for welded stainless steel liners in accordance with 8.6 of EN 13322-2:2003, and meet the requirements therein;

d) bend tests for welded stainless steel liners in accordance with 8.5 of EN 13322-2:2003, and for welded aluminium alloy liners in accordance with 7.2.5 to 7.2.7 of EN 12862:2000, and meet the requirements therein;

e) macroscopic examinations for welded stainless steel liners in accordance with 8.7 of EN 13322-2:2003, and meet the requirements therein;

f) when a protective coating is a part of the design, the following two tests shall be performed:

   1) the thickness of the coating shall be measured in accordance with ISO 2808 and shall meet the requirements of the design

   2) a coating adhesion strength shall be measured in accordance with ISO 4624, and shall have a minimum rating of 4 when measured using either test method A or B, as appropriate.

   Where the coating fails to meet these requirements, the batch shall be 100 % inspected to remove similarly defectively coated containers. The coating on all defectively coated containers shall be stripped using a method that does not affect the integrity of the composite wrapping, and recoated. The above two tests shall then be repeated.

For Type 4 designs, a further container, or liner, or sample representative of a finished container, shall be subjected to the following tests:

a) verification of the critical dimensions of the design;

b) yield strength and ultimate elongation of the plastic liner material shall be determined in accordance with 5.1.6.5 and meet the requirements therein;

c) softening temperature of the plastic liner shall be tested in accordance with 5.1.6.5, and meet the requirements of the design;

d) when a protective coating is a part of the design, the following two tests shall be performed:

   1) the thickness of the coating shall be measured in accordance with ISO 2808 and shall meet the requirements of the design

   2) a coating adhesion strength shall be measured in accordance with ISO 4624, and shall have a minimum rating of 4 when measured using either test method A or B, as appropriate.

   Where the coating fails to meet these requirements, the batch shall be 100 % inspected to remove similarly defectively coated containers. The coating on all defectively coated containers shall be stripped using a method that does not affect the integrity of the composite wrapping, and recoated. The above two tests shall then be repeated.

All containers and liners represented by a batch test that fails to meet the requirements specified shall follow the procedures specified in 5.1.8.3.

5.1.8.3 **Failure to meet batch and production test requirements**: In the event of failure to meet test requirements, re-testing or re-heat treatment and re-testing shall be carried out as follows:

a) if there is evidence of a fault in carrying out a test, or an error of measurement, a further test of the same kind shall be performed. If the result of this test is satisfactory, the first test shall be ignored;

b) if the test has been carried out in a satisfactory manner, the cause of test failure shall be identified.

   1) If the failure is considered to be due to the applied heat treatment, the manufacturer may subject all the metal containers or liners implicated by the failure to a further heat treatment, i.e. if the failure is in batch test, the test failure shall require re-heat treatment of all the represented metal containers or liners prior to re-testing; however if the failure occurs sporadically in a production test, then only those metal containers or liners which fail the test shall require re-heat treatment and re-testing.

      Only the appropriate batch tests needed to prove the acceptability of the new batch shall be performed again. If one or more tests prove unsatisfactory, all metal containers or liners of the batch shall be rejected.

   2) If the failure is due to a cause other than the heat treatment applied, all defective metal containers or liners shall be either rejected or repaired. Repaired metal containers or liners that pass the test(s) required for the repair shall be treated as a separate new batch.

5.1.9 Production tests

Production verifications and tests shall be carried out as follows on all containers produced in a batch.

Each container shall be subject to the following verifications during manufacturing or after completion:

a) NDE of metallic containers and liners in accordance with Annex B of ISO 9809-1:1999, or Annex C of EN 1964-3:2000, or Annex B of EN 13322-2:2003 as appropriate, or a demonstrated equivalent method, to confirm that the maximum defect size does not exceed the size specified in the design. The NDE method shall be capable of detecting the maximum defect size allowed;

b) examination of welded stainless steel liners in accordance with 6.8.2 of EN 13322-2:2003, and welded aluminium alloy liners in accordance with 6.2.1 (second paragraph) and 6.2.3 of EN 12862:2000;

c) inspection of plastic liners to confirm that the maximum defect size present is less than the size specified in the design;

d) the verification of critical dimensions and mass of the finished containers, liners and over-wrapping are within design tolerances;

e) verification of conformance to the manufacturer’s specified surface finish with special attention to deep drawn surfaces and folds or laps in the neck or shoulder of forged or spun end enclosures or openings;

f) verification of the markings;

g) hardness tests carried out on the parallel wall at the centre, and at one of the domed ends of each container or liner in accordance with ISO 6506-1, or using an equivalent method. The test shall be carried out after the final heat treatment and the hardness values thus determined shall be in the range specified for the design.

h) hydraulic test of finished containers with the container hydraulically tested to at least 1,5 NWP. In no case shall the test pressure exceed the auto-frettage pressure. Pressure shall be maintained for 30 seconds or sufficiently longer to ensure complete expansion. If the test pressure cannot be maintained due to failure of the test apparatus, the test shall be repeated at a pressure increased by 0,7 MPa. No more than two such repeat tests shall be performed. For Type 1, Type 2 and Type 3 designs, the permanent volumetric expansion shall not exceed the limit of permanent volumetric expansion specified by the container manufacturer for the test pressure used. In addition, in no case shall the permanent expansion exceed 5 % of the total volumetric expansion measured under the test pressure. For Type 4 designs the manufacturer shall define the appropriate limit of elastic expansion for the test pressure used, but in no case shall the elastic expansion of any container exceed the average batch value by more than 10 %. Containers not meeting the defined limit of permanent volumetric expansion or elastic expansion as specified by the container manufacturer shall be rejected and rendered unserviceable.

i) leak test on Type 4 containers or liners with the container thoroughly dried. Pressurize the container to NWP with hydrogen, or dry air or nitrogen containing a detectable gas such as helium. Any leakage detected shall be cause for rejection.

NOTE Leakage is the release of gas through a crack, pore, unbond, or similar defect. Permeation through the wall in conformity to 5.1.7.6 is not considered to be leakage.

6 Markings

On each container the manufacturer shall provide clear permanent markings. The font size used on the markings shall be a minimum 5 mm high on containers with a diameter greater than or equal to 140 mm, and greater than 2,5 mm high on containers with a diameter of less than 140 mm. Marking shall be made either by labels incorporated into resin coatings, labels attached by adhesive, low stress stamps used on the thickened ends of Type 1 and Type 2 designs, or any combination of the above. Adhesive labels and their application shall be in accordance with ISO 7225. Multiple labels may be used and should be located such that they are not obscured by mounting brackets.

Each container shall be permanently marked with the following information:

a) "H_2 ONLY";

b) "DO NOT USE AFTER XXXX-XX", where XXXX-XX identifies the year and the month of expiry;

c) manufacturer’s identification;

d) container identification (a serial number unique for every container);

e) water capacity (l);

f) "USE ONLY MANUFACTURER-APPROVED NON-RECLOSING THERMALLY ACTIVATED PRESSURE RELIEF DEVICE";

g) date of manufacture (year in four digits and month in two digits);

h) NWP (MPa) at temperature (°C);

i) if labels are used, there is an additional requirement for a unique identification number and the manufacturer’s identification to be permanently marked on an exposed metal surface in order to permit tracing in the event that the label is destroyed;

j) if the container has a reduced number of filling cycles per 5.1.3 then the container shall additionally be marked “USE ONLY WITH TAMPER-PROOF FILLING CYCLE COUNTER SYSTEM”;

The expiry date may be applied to the containers at the time of dispatch, provided that the containers have been stored in a dry location without internal pressure. The period between the dispatch date and the expiry date shall not exceed the specified service life. The markings shall be placed in the listed sequence but the specific arrangement may be varied to match the space available.